REPORT 49B

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMELIORATION

DU MILIEU PEDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

LAND RESHAPING OF LOWLAND CLAY SOILS

II. MODELLING REPORT

FINAL REPORT

May, 1992

Prepared by: Andrew H. Marshall
in association with
CAN-AG ENTERPRISES,
Guelph, Ontario

Under the Direction of: ECOLOGICAL SERVICES FOR PLANNING LIMITED,
Guelph, Ontario - Subprogram Manager For TED

On Behalf of: AGRICULTURE CANADA
RESEARCH STATION,
HARROW, ONTARIO N0R 1G0

Recycled Paper

Papier recyclé

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The land planing studies, which were carried out by Can-Ag Enterprises Limited, were mathematically modelled using a modified version of the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS, Ver. 1.7) model. This modelling assignment focused on the first phase of model application, the prediction of overland flow episodes, and was based on a procedure which encompassed five areas of model development and application. These areas included problem identification, stated objective, development of method, results and evaluation of results.

Based on this procedure, 116 out of 130 observed episodes of overland flow were predicted for the twelve fields in the land planing studies for the time period from April'89 to September'90. In addition, 38 predictions were made which could not be explained, i.e. the failure of monitoring equipment. These results were dependent on a number of factors including the proximity of an agricultural field to precipitation measurement as well as the seasonal variation in infiltration characteristics of heavy clay soils.

The predictions of overland flow episodes resulted from a novel approach of applying the CREAMS Ver. 1.7 model to agricultural fields across seasons. This approach provided a solid basis for the next phase of modelling application: an emphasis on the prediction of flow quantities and sediment and phosphorus concentrations and loadings. The framework for such an emphasis could easily be patterned on the framework developed in this assignment, the first phase of model application.

1. INTRODUCTION

The development of technology to contain phosphorus, at its' point of application, requires knowledge about the factors that affect surface and sub-surface drainage of agricultural lands (Frere et al., 1982). Some of these factors are measurable in quantitative terms and within limits, are controllable by amendment and cultural practice. Examples are surface slope, depression storage, drainage means and pathways (Huggins and Burney, 1982), surface roughness (Smith and Williams, 1980) and canopy (U.S. Soil Conservation Service, 1974).

Other factors are set by soil physical characteristics and include infiltration capacity (Horton, 1940), soil water storage capacity (Holtan, 1961), and soil water transport (Green and Ampt, 1911). These parameters regulate the storage and transport of water within the soil profile, affect the occurrence of ponding in the soil, and are not amendable to control in the general sense. Additionally, these parameters are thought to vary seasonally (Beck, 1987), but their variability across seasons in imperfectly understood at this time; quantitative estimates for the parameters are not readily available, at the field scale, for individual seasons.

This lack of knowledge constrains the ability to estimate seasonal variation of surface and sub-surface drainage flows. This constraint is accompanied by the inability to describe seasonal trends in phosphorus transport. Consequently, knowledge, which is required to develop technology for containment of phosphorus within agricultural land, is not readily at hand.

In this study, factors which affect surface and sub-surface flows on the twelve fields involved in Can-Ag Enterprises Limited's Land Planing studies were

investigated. Examination of data from the monitoring systems located at each of the field site in the studies provided insight into the factors which affected the flows.

2. OBJECTIVE

The objective of this study was to determine empirical values for field parameters. These parameters affect the estimations of surface and sub-surface drainage of agricultural lands, across seasons in south-western Ontario.

Three criteria were be used to select empirical values for parameters in question. These were: values provide for correct prediction of observed occurrences of surface and sub-surface drainage episodes; values are consistent with current knowledge about parameters; and the results from this study provide a reliable technical basis for subsequent modelling of flow rate, flow volumes and related phosphorus concentrations at the field scale.

3. METHOD

The determination of empirical values for field parameters were carried out in four related steps. These were: comparison of available methods used in representing field parameters, examination of field data available from Can-Ag's Land Planing study, modification of the CREAMS model to allow for changes in parameters by season, and development of a procedure for determining the empirical values for field parameters. The first three steps were prerequisite to the fourth step. Comparison of the available methods produced the optimal method for representing field parameters. Examination of field data from Can-Ag's Land Planing studies provided information required to represent the field conditions. Modification of CREAMS enabled the model to better represent the field conditions as they varied with season. Method for determining the empirical values for field parameters could then be developed and completed.

(a) Comparison of Methods Used to Represent Field Parameters

Five mathematical models which represented surface and sub-surface flows at the field scale were evaluated and compared. Models were evaluated with respect to hydrologic processes (infiltration, evapotranspiration, overland flow, sub-surface flow, precipitation) and other processes (ie. erosion, chemical transport, etc.) which they represented. Models were compared, and the optimal model was then used to represent the field conditions for the duration of the study.

(b) Examination of Field Data from Can-Ag's Land Planing Studies

Can-Ag's studies are presented in two parts: study area definition and field observations. Definition of the study area includes location of individual fields and

their physical features. The field observation part includes the types of observations made in the field and how these observations were performed.

(i) Study Area

The field studies were carried out on four sites, located in Essex and Kent counties in south-western Ontario shown in Figure 3.1. Each site contained either a Brookston or Toledo soil series and field pairings of a planed field and an unplaned field. Field pairings for each of the four sites are shown in Figures 3.2, 3.3, 3.4, & 3.5 that follow.

(ii) Field Observations

Information about each field in the study area was obtained according to the following general procedure. At the beginning of the land planing studies, soil pits were dug in each field, the soil profile was observed, and these observations were recorded. Also, soil samples were taken for laboratory analysis of texture, and field area and slope characteristics were surveyed.

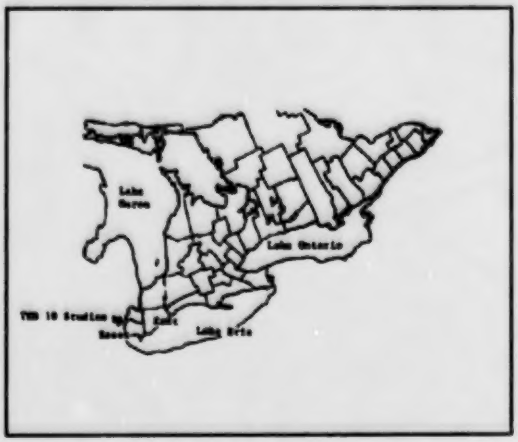


Figure 3.1 Location of the land planing Studies

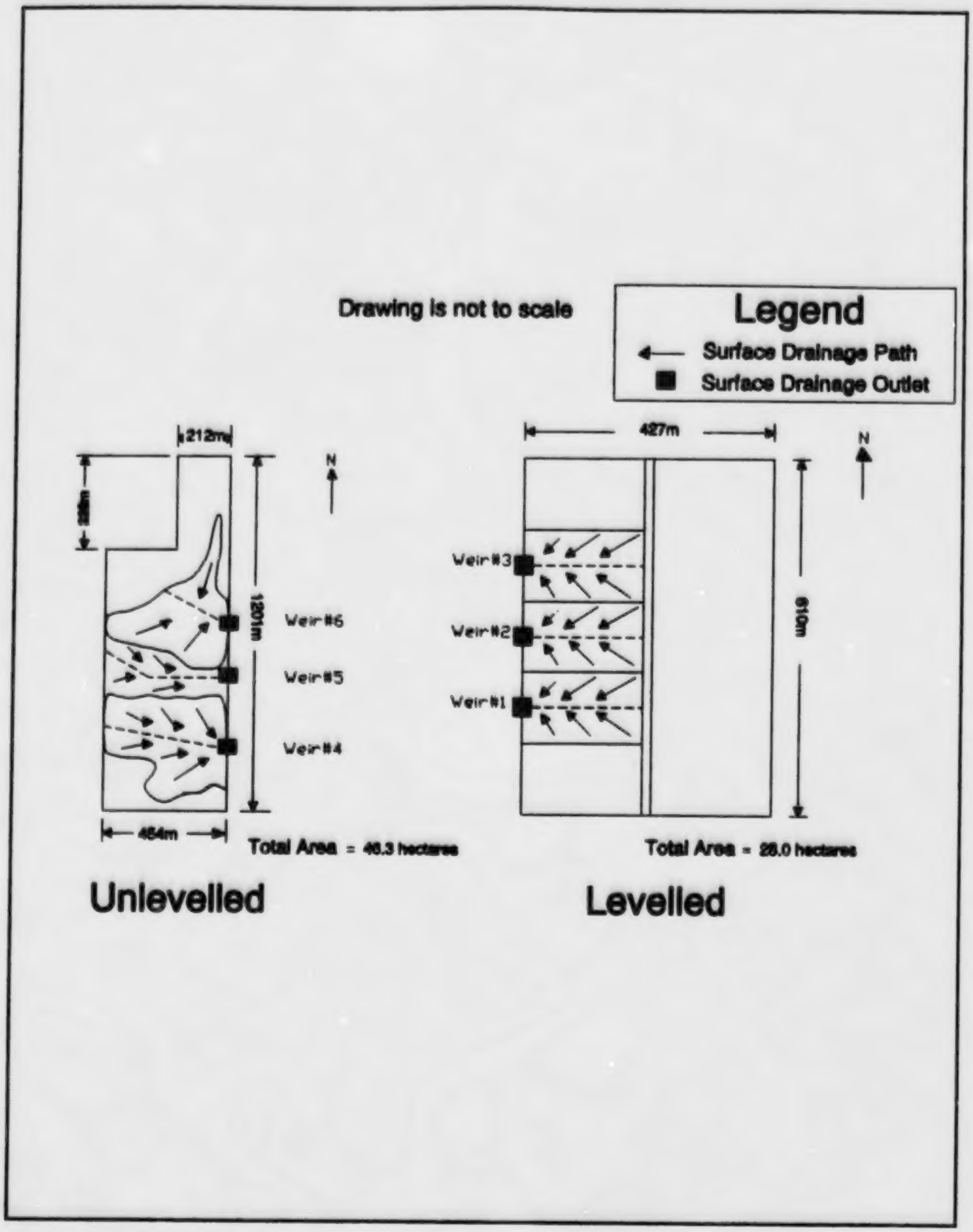


Figure 3.2 Field Pairings for AFF Farms Ltd Field Site

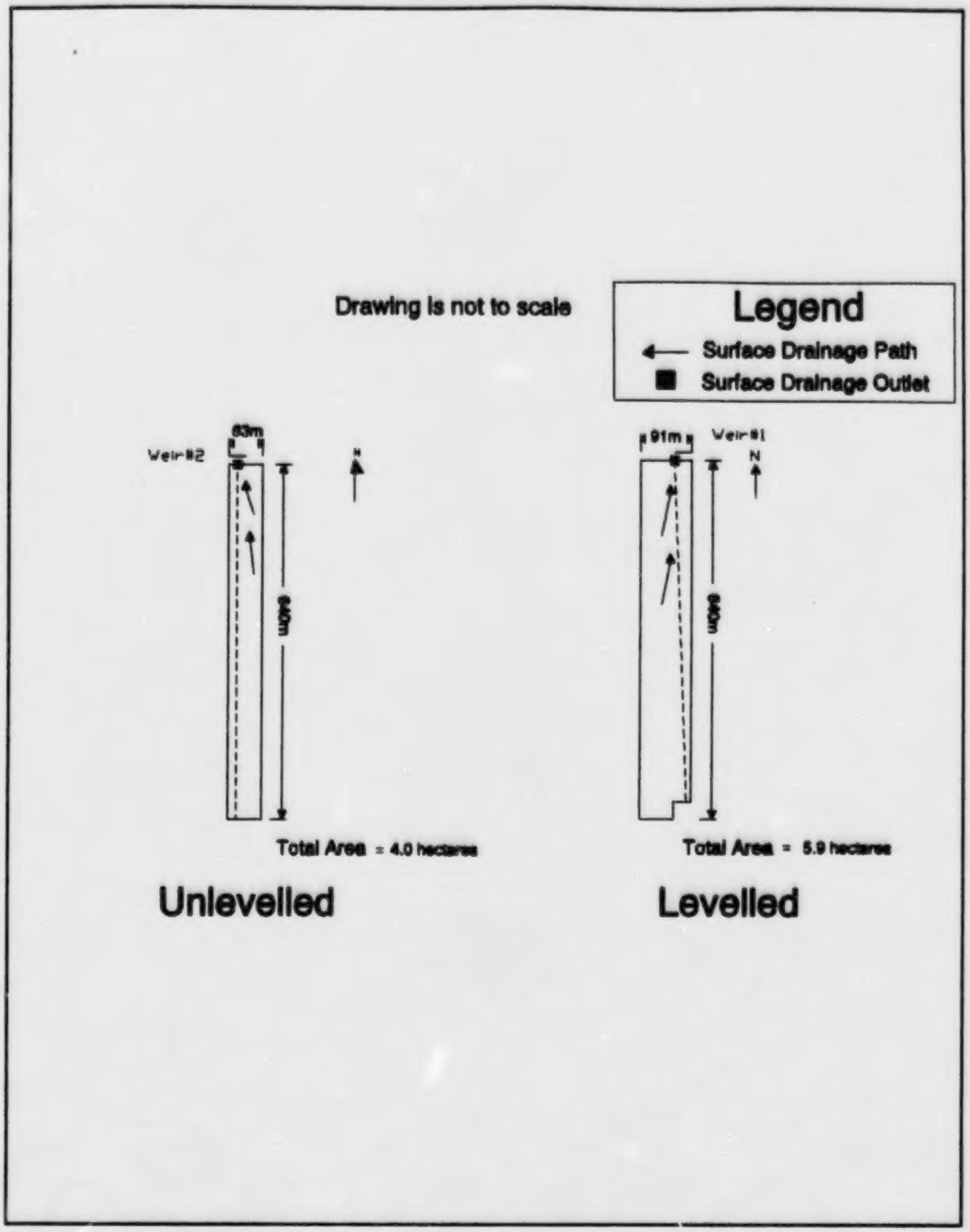


Figure 3.3 Field Pairings for Lanoue Field Site

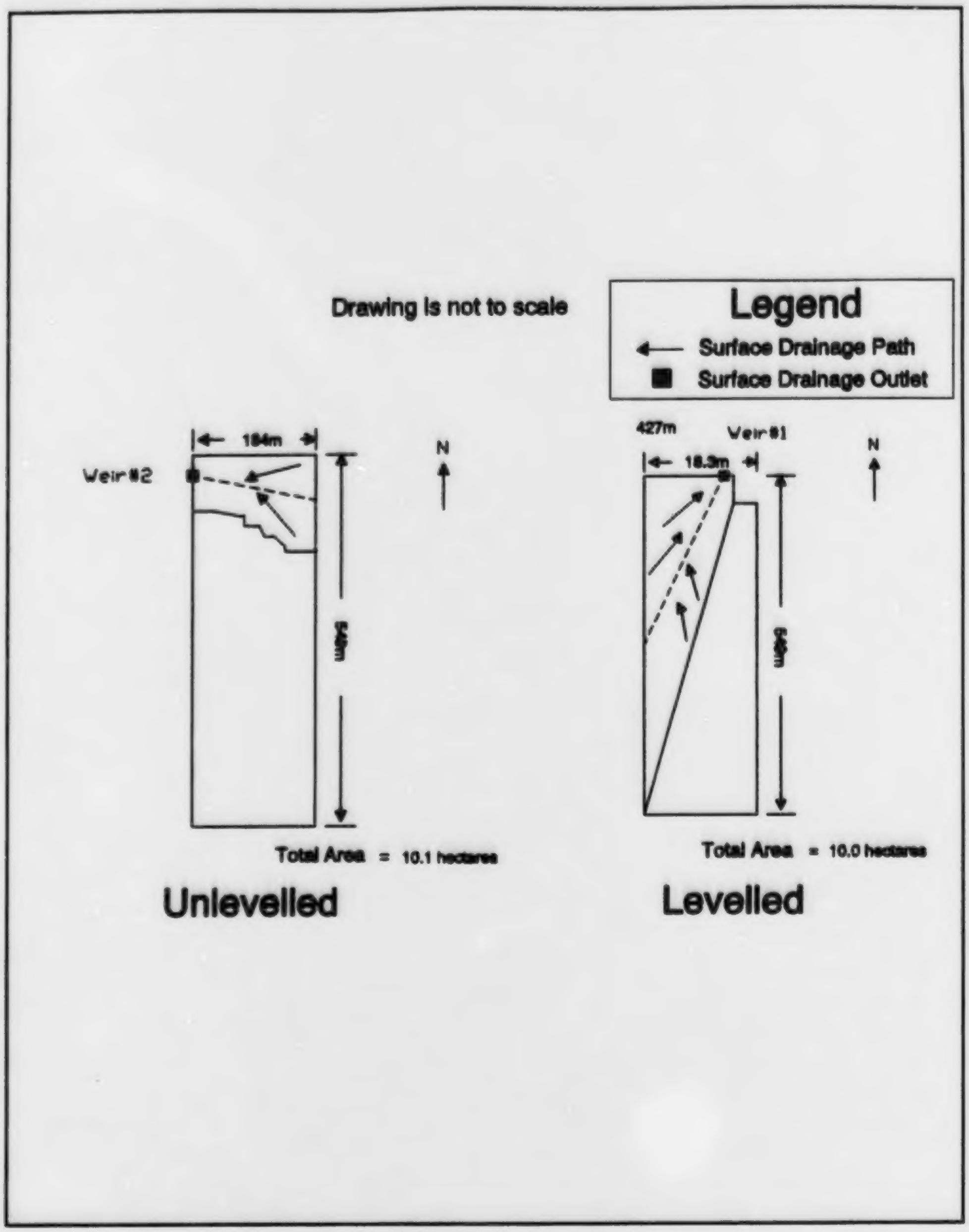


Figure 3.4 Field Pairings for Barrette Field Site

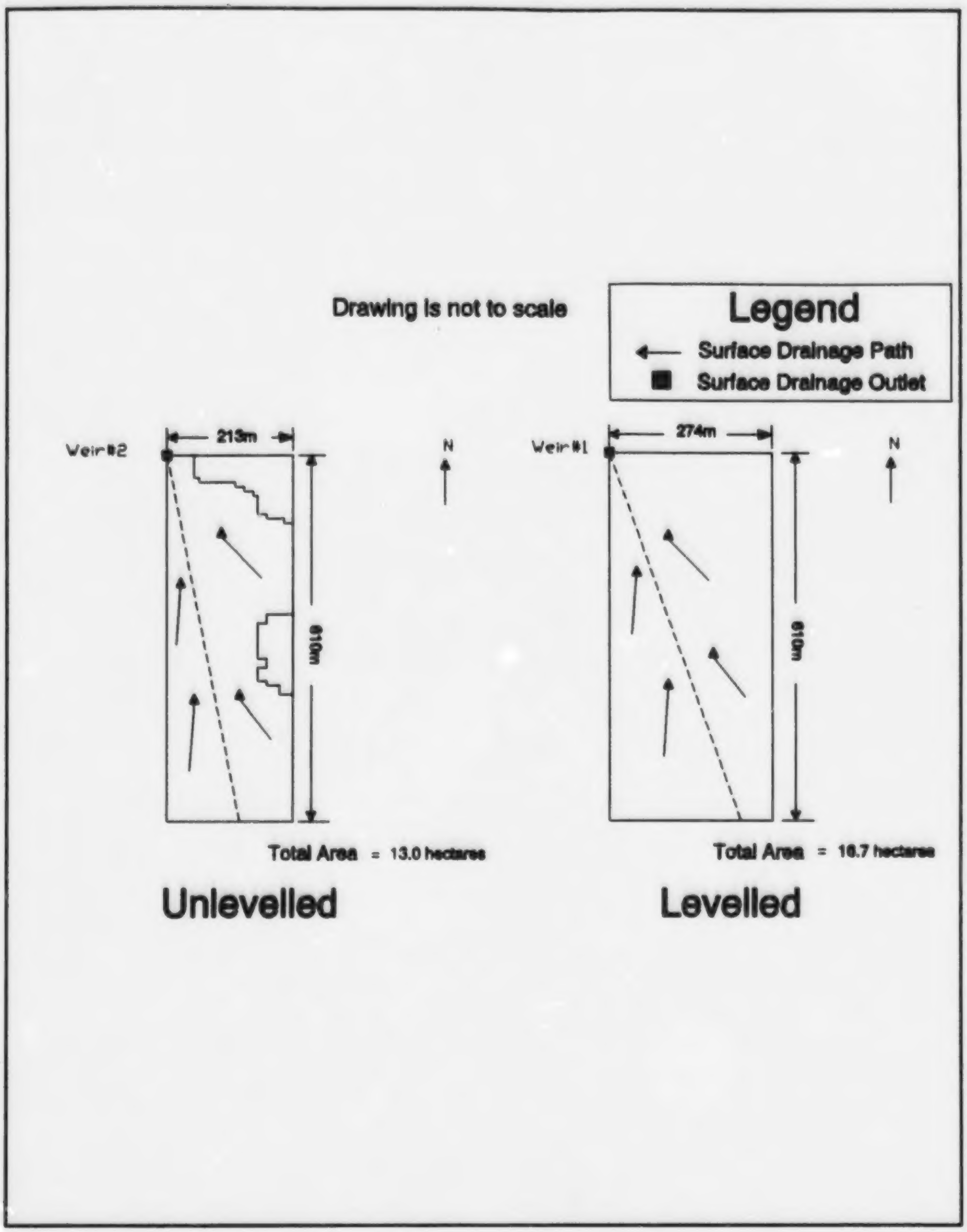


Figure 3.5 Field Pairings for Doyle Field Site

Throughout the land planing studies, hydrologic data and cropping practice characteristics were observed for each field. Rainfall was observed by the use of three raingauges located in the study area. Two of the sites had weighing type raingauges; the other site had a tipping bucket raingauge. All the raingauges measured rain depth with respect to time with resolution possible at a minimum interval of five minutes. During the winter period, raingauges made water equivalent measurements of snowfall. Figure 3.6 shows the location of the raingauges with respect to the fields in the land planing studies.

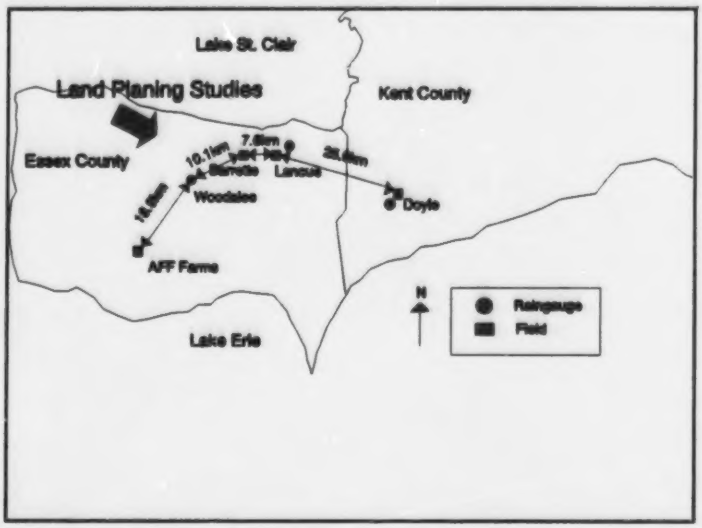


Figure 3.6 Raingauge Location

Hydrologic outputs were continually observed through the use of weirs with depth of flow gauges and water quality samplers. Instruments were located at overland flow outlets. Weirs and gauges for the depth of water above the weir crest were installed for each field in the land planing studies and measured the

depth of water above the weir with respect to time. Automated water samplers from Isco Incorporated R were installed for six fields in the study and collected overland flow samples at hourly intervals. When an Isco sampler was not installed for a field, overland flow samples were taken by a technician periodically through a overland flow episode. Figure 3.7 shows the setup of these instruments. The location of each weir and water-depth gauge is shown in Figures 3.2, 3.3, 3.4 & 3.5.

Cultural practices were observed for each field throughout the land planing studies. At each field site, farm operators observed and recorded the timing of field operations, the type of machine used, the activity, and crop detail.

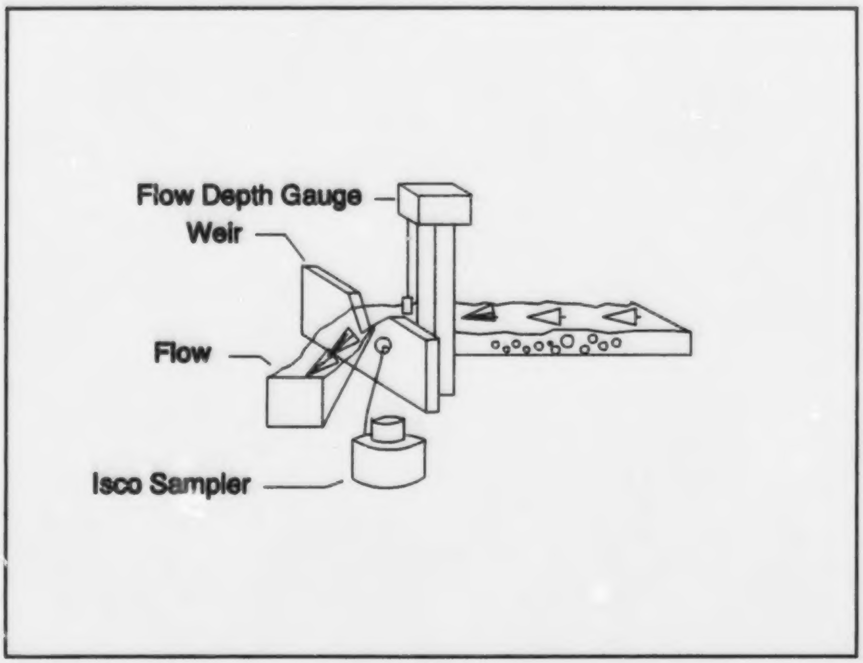


Figure 3.7 Instrumental Setup at Surface Drainage Outlet

(c) Modifying the CREAMS Model

The CREAMS model comprises three components: hydrologic, erosion and chemical. A full description of the CREAMS model is provided by Knisel (1980), and Figure 3.8 shows the relationship between these three components. The hydrologic component describes the major hydraulic processes which occur during and between rainfall events. The erosion component describes the daily sediment yield in kg/ha during rainfall events and is partially based on calculations made in the hydrologic component. The chemical component describes the phosphorus in overland runoff in kg/ha and ppm and the phosphorus with sediment in kg/ha and is partially based on calculations made in the erosion component.

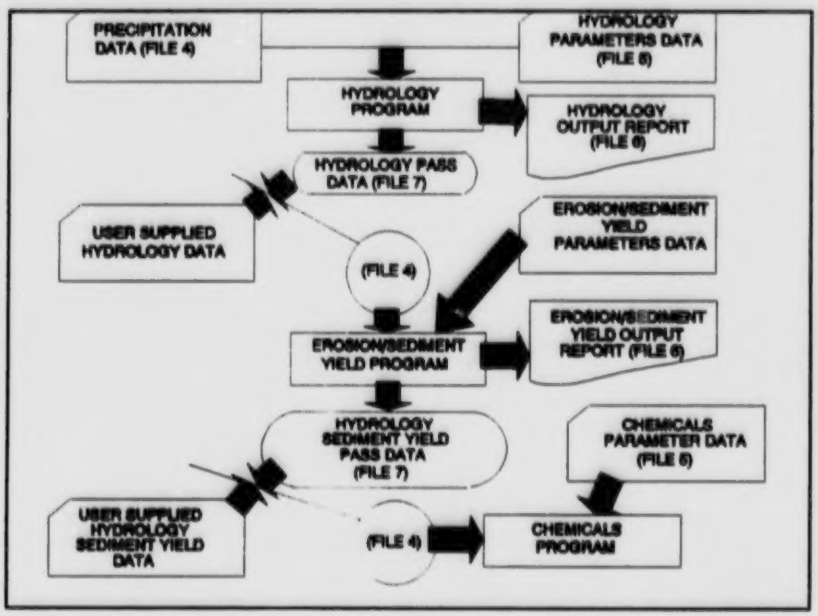


Figure 3.8 Schematic Representation of CREAMS (from Knisel, 1980)

The hydrologic component of CREAMS has two options for representing the hydraulic processes which occur during rainfall events: the breakpoint rainfall option uses breakpoint accumulation of rainfall (or hourly amounts), coupled with Green and Ampt infiltrability to calculate overland flow; the daily rain option uses total rain amounts with the SCS curve number method of calculation of overland runoff. Since Can-Ag's land planing studies provided data which could represent rainfall depth every 30 minute time interval, the breakpoint rainfall option was used.

The hydrologic component of CREAMS has two main parts which are essential in predicting the occurrence of overland flows: description of hydraulic processes during rainfall events and description of hydraulic processes between rainfall events. During rainfall events, if the temperature is above freezing, the breakpoint rainfall option uses the Green and Ampt (1911) formula to calculate the amount of water which infiltrates into the soil. The infiltration calculation takes place at 30 minute time intervals in which rainfall depth is represented, and an overland flow profile occurs when the amount of precipitation exceeds the amount of infiltration during the time interval. The profile storage depth h(cm) is given by Equation 3.1.

If the temperature is below freezing, rainfall depth is added to the total snow storage, and infiltration and overland flow are not calculated. During rainfall events, if the temperature is above freezing, all of the water infiltrating into the soil is an input in the soil water tabulation. Meanwhile plant and soil evaporation and percolation are outputs in the soil water tabulation.

$$h = \left(\frac{ix}{CS^{1/2}}\right)^m \ldots\ldots (1)$$

where: i: difference between precipitation and infiltration (cm)
x: length of flow plane (m)
m: uniform flow coefficient
C: Chezy roughness coefficient (derived from Manning's n)
S: field slope (m/m)

Equation 3.1 Profile Storage Depth

Soil and plant evaporation calculations are based on the evapotranspiration model proposed by Ritchie (1972), and percolation is calculated when the soil water content in the specified soil water area is greater than field capacity. However, if the temperature is below freezing, infiltration, plant and soil evaporation and percolation are not calculated, and soil water content remains unchanged.

Between rainfall events, the hydrologic component tabulates the soil water content on a daily interval. Soil water inputs are given by snowmelt, and soil water outputs are given by plant and soil evaporation and percolation. Snowmelt input occurs when snow storage exists and the daily temperature, which is calculated on a daily basis using a curve fitted to monthly average value, is above freezing. However, if temperature is below freezing, the soil water content remains unchanged.

Application of the hydrologic component to determine the empirical values of parameters which affect overland flow episodes from season to season. The version of CREAMS obtained did not allow for seasonal changes in parameters. In order to change model parameters, the hydrologic component of CREAMS

Version 1.7 was modified to disclose estimates for daily soil water content. The estimate for soil water at the end of one season was thus available to be used to establish the soil water value at the beginning of the next season. As well, changed parametric values were established at the start of the next modelled season, and consequently, the model was run in a stepwise continuous fashion.

(d) Determining the Empirical Values for Parameters

To determine the empirical values for the CREAMS model parameters which affect the occurrence of overland flow, a four part procedure was developed. The four parts are parametric analysis, sensitivity analysis, calibration and phosphorus predictions. In the parametric analysis, each parameter was defined and given an initial empirical value from an associated data source. In the sensitivity analysis, the effect of the range in empirical values of each parameter on modelled surface flow was established. In the calibration part, the empirical values for parameters affecting surface flow were optimized and in the phosphorus predictions part, the ability to make concurrent predictions of phosphorus transport with hydrologic transport was determined.

(i) Parametric Analysis

The CREAMS hydrologic component was applied to each of the fields in Can-Ag's land planing studies, and for each application, model parameters were investigated in five groups. These were precipitation parameters, solar & temperature parameters, hydrologic parameters, crop parameters and soil parameters. A group comprises parameters for which numerical values are determined from the same data source.

The precipitation group contained parameters determined from observations recorded by the three raingauges shown in Figure 3.6. The solar & temperature group contained parameters that relied on observations at the Agriculture Canada Research Station at Harrow, Ontario. The hydrology group consisted of parameters determined from observations recorded at field locations shown in Figures 3.2 to 3.5 inclusive. The crop group is based upon observations made by farm operators, and the soil group is based upon observations made from soil pit and related textural classifications. Field scale estimates for effective saturated conductivity in the Toledo soil were not available, and values for Brookston soil were used in their absence.

The five parameter groups are set out in Table 3.1 with their data sources. Numerical values for the parameters listed in Table 3.1 were determined for the period from Julian day 90, 1989 to Julian day 260, 1990 (March 31, 1990 to Sept 17, 1990). It is important to note that there is some ambiguity over the component's FUL parameter. This ambiguity is described in Appendix B.

For each application of the CREAMS hydrologic component to the study fields, parameters were examined with respect to the initial observations and continuous observations made at the data sources where appropriate. Numerical values, which represented both initial and day to day observations, were determined for each parameter in the model. For example, numerical values, which described variations in precipitation, temperature, radiation and leaf area index parameters, were determined for time intervals between Julian day 90, 1989 and Julian day 260, 1990, whereas the remainder of parametric values were only

determined initially. The continuous model output, resulting from the application of these numerical values, was observed and recorded.

(ii) Sensitivity Analysis

The CREAMS hydrologic component was applied in a sensitivity analysis based upon the parameter groups given in Table 3.1. As in the parametric analysis, each group consisted of parameters that shared the same data source. However, unlike the parametric analysis, maximum and minimum values for each parameter were interpreted from the observed data and applied in the following way to the sensitivity analysis.

Maximum and minimum numerical values, which represented the observed range in a parameter at the field scale over the course of one year, were interpreted from the associated data sources. In the case of rainfall, the observed depth of rainfall was assumed to be representative of actual depth of rainfall, but the interval at which rainfall was defined was varied between 60 minute, 30 minute and 15 minute intervals. The interval was varied by changing data in the precipitation data file; data which showed the cumulative depth of precipitation for every 30 minute interval were changed to data which showed the cumulative depth of precipitation for every 60 minute interval and then for every 15 minute interval. For an individual parameter, the numerical value was varied between its maximum and minimum value, while leaving the numerical value for all other parameters at their values set during the parametric analysis. Results from continuous modelling for the range in each parameter, taken one at a time, were observed and recorded. By this approach, the parameters that affected the modelling output were identified.

Table 3.1 Parameter Groups and Associated Sources

Parameter Group	Data Source	Parameter Name	Parameter Definition
Precipitation	Precipitation Gauges	PREC	Precipitation
Solar/Temperature	Agriculture Canada	TEMP	ave. monthly temp.
		RADI	ave. monthly radiation
Hydrologic	Field Surveys	DACRE	field area (acres)
		SLOPE	ave. field slope
		XLP	length of flow plane
Crop	Farmer's Records	LAI	leaf area index
		DP	depth of root zone
		RMN	roughness coefficient
		GR	winter cover factor (snow cover condition)
Soil	Soil Pits, Textural Analysis,	RC	effective saturated conductivity
	and	GA	effective capillary tension
	Previous Research	POROS	soil porosity
		BST	portion of plant-available water storage filled at start
		DS	depth of surface soil
		BR15	immobile soil water content
		FUL	portion of plant-available water filled at field capacity
		CONA	soil evaporation parameter

(iii) Calibration

The parametric analysis and the sensitivity analysis were applied to differentiate two groups of modelling parameters. The two groups are:

-those parameters that do not affect the number of predicted episodes of overland flow according to the range determined in their numerical values,

-those parameters that do affect the number of predicted episodes of overland flow according to the range determined in their numerical values.

Calibration of the modelling investigations was based upon the latter group of parameters in the following way.

Within the range of observed values for the parameters that affect the number of predicted episodes of overland flow, seasonal values were determined from previous studies and field and crop conditions in the study area. In this process, numerical values for field parameters were not adjusted to account for differences between planed and unplaned fields. Seasonal values were established at the beginning of each application to a seasonal interval. At the end of the application, seasonal values were changed, and the estimate for the daily soil water value in the last day of the seasonal interval was used to establish the initial soil water content of the application to the next seasonal interval. The seasonal values used for each seasonal interval were calibrated to minimize the discrepancy between predicted and observed episodes of overland flow.

(iv) Phosphorus Predictions

In the CREAMS algorithms any prediction of a episode of overland flow produces a concurrent prediction of phosphorus production. This phosphorus prediction was tested by application of the modified CREAMS hydrologic component, the erosion and the chemical components to Lanoue Weir #1 field for the same period as that for which episodes of overland flow were predicted. Parameters in the modified hydrologic component were given the same values used to predict episodes, and parameters in the erosion and chemicals components were given numerical values representative of field and crop conditions observed in the land planing studies.

4. RESULTS

Results from the method of determining empirical values for field parameters that affect overland flow episodes are organized in four parts. These are: comparison of available methods used in representing field parameters, examination of field data from Can-Ag's land planing studies, a modification of the CREAMS model, and results from the development of a procedure for determining the empirical values for field parameters. As stated in the method, the first three parts are prerequisite to the fourth. Comparison of the available methods produced the optimal method for representing field parameters. The examination of field data from Can-Ag's land planing studies provided the information required to represent field conditions in the CREAMS model. The modification of CREAMS was required to insert seasonal changes in parameters during stepwise continuous runs of the hydrologic component of CREAMS. Using only the hydrologic component of CREAMS with parameter values consistent with observed field conditions, the feasibility of using CREAMS to model the occurrence of episodes of overland flow across seasons and across fields within a season was evaluated.

(a) Comparison of Methods Used to Represent Field Parameters

Five mathematical models which represented surface and sub-surface flows at the field scale were evaluated with respect to the types of processes represented within the model. These models were: Cooke (1986), Peters (1987), the Guelph Agricultural Watershed Storm Event Runoff (GAWSER) model (Schroeter

and Whiteley, 1988), DRAINMOD (Skaggs, 1980) and the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980). Table 4.1 gives the types of processes represented by each model.

Table 4.1 Model Comparison

Model	Sub-surface Flow	Surface Flow	Evaporation Comp.	Winter Comp.	Sediment & Chemical
Cooke (1986)	YES	NO	-	-	-
Peters (1987)	YES	NO	-	-	-
GAWSER	NO	YES	NO	YES	NO
DRAINMOD	YES	YES	YES	NO	NO
CREAMS	NO	YES	YES	YES	YES

The feasibility of using Cooke (1986), Peters (1987), GAWSER, DRAINMOD or CREAMS for continuous representation of the circumstances under which surface and sub-surface flows might occur on a field scale has not been demonstrated to date. The Cooke (1986) and Peters (1987) fail to represent surface drainage episodes. The GAWSER model fails to represent sub-surface drainage episodes and the circumstances between rainfall events (evaporation component). The DRAINMOD model fails to represent field circumstances during the winter period, and the CREAMS model fails to represent subsurface drainage episodes in the tile drains.

Still, CREAMS is a continuous model of surface and sub-surface conditions that affect both overland and sub-surface drainage episodes on the field scale. Also it combines hydrologic modelling with modelling of erosion and phosphorus transport. The CREAMS model has been applied to conditions in southern Ontario by researchers at the University of Guelph (Rudra, Dickinson and Wall, 1985 & 1989). Due to these advantages over the other available models, CREAMS was selected for this study.

The investigation of using the CREAMS model focused on the circumstances under which individual drainage episodes occur. Since the CREAMS model directly represents only the overland flow episodes, the investigation was limited to modelling circumstances under which overland flow episodes occurred. The model was used in a way that attempts to represent these circumstances despite temporal and spatial variation in factors that affect the occurrence of overland flows.

(b) Field Data from Can-Ag's Land Planing Studies

The study area and intended field observations are described in the experimental design for the Land Planing studies (Can-Ag Enterprises Ltd., 1988). The experimental design and field information collected during the Land Planing studies are given in Appendix A.

(c) Modifying the CREAMS Model

As described in the method, the hydrologic component of CREAMS was modified to disclose estimates for daily soil water storage. Details of this modification, including changes in the CREAMS source code and results from this modification, are listed in Appendix B. The soil water storage given by the model at the end of one season was entered as the initial soil water status for the following season in the stepwise continuous form of the model used in this study. An example of the soil water values transferred is also given in Appendix B.

(d) Determining the Empirical Values for Parameters

The feasibility of using the CREAMS model to represent the circumstances under which episodes of overland flow might occur in the study area was assessed with respect to the criteria listed in Chapter 2. To determine the empirical values for the CREAMS model parameters which affect the occurrence of overland flow, a four part procedure was developed. The four parts are parametric analysis, sensitivity analysis, calibration and phosphorus predictions. In the parametric analysis, each parameters was defined and given an initial empirical value from an associated data source. In the sensitivity analysis, the effect of the range in empirical values of each parameter on modelled surface flow was established. In the calibration part, the empirical values for parameters affecting surface flow were optimized and in the phosphorus predictions part, the ability to make concurrent predictions of phosphorus transport with hydrologic transport was determined.

(i) Parametric Analysis

The modified version of the CREAMS hydrologic component was applied to each of the fields in the study area. For each field, five different groups of model parameters were tested. These were: precipitation parameters, solar & temperature parameters, hydrologic parameters, crop parameters and soil parameters. Each group included parameters determined from the same data source. The precipitation parameter group included rainfall data obtained from the raingauges shown in Figure 3.6. The breakpoint rainfall option of the CREAMS model was used. Depth of rainfall was interpreted for thirty minute intervals. Table 4.2 gives the raingauge site related to each field and gauge proximity to the field.

Table 4.2 Raingauge Site and Proximity

Field Application	Raingauge Site	Proximity
1. Lanoue W1	Lanoue	0.8km
2. Lanoue W2	Lanoue	0.8km
3. Barrette W1	Lanoue	7.6km
4. Barrette W2	Lanoue	7.6km
5. Doyle W1	Doyle	0.0km
6. Doyle W2	Doyle	0.0km
7. AFF Farms W1	Woodslee	18.8km
8. AFF Farms W2	Woodslee	18.8km
9. AFF Farms W3	Woodslee	18.8km
10. AFF Farms W4	Woodslee	18.8km
11. AFF Farms W5	Woodslee	18.8km
12. AFF Farms W6	Woodslee	18.8km

Precipitation records associated with each raingauge site were sometimes incomplete. When recorded observations for a specific raingauge were incomplete, observations from the next closest raingauge site were used.

The solar & temperature group included temperature and solar radiation parameters, and for each field, numerical values for the average monthly temperature were obtained from the seventy-three year average of mean monthly temperatures recorded at the Atmospheric Environment Service Station in Harrow, Ontario. Numerical values for the average monthly radiation were taken from the CREAMS manual (default: East Lansing, Michigan) since the recordings at Harrow station were not interpretable. Table 4.3 gives the average monthly numerical values obtained for the temperature and solar radiation parameters.

Table 4.3 Temperature and Solar Radiation Values

Month	Temperature (Celsius)	Solar Radiation (langleys)
January	-4.8	121.0
February	-3.8	210.0
March	1.2	309.0
April	7.9	369.0
May	14.2	483.0
June	19.7	547.0
July	22.0	540.0
August	21.2	466.0
September	17.5	373.0
October	11.3	255.0
November	4.5	136.0
December	-1.7	108.0

The hydrology group included estimates of the area, slope and slope length for individual fields from field surveys by Can-Ag field staff. For each field, numerical values for the area, slope and slope length were derived from survey observations. Also, MacMillan (1990) surveyed unplaned fields on Barrette's, Doyle's and AFF Farm Ltd's to determine the area contributing to the overland flow through the weirs. Table 4.4 gives numerical values for the hydrology parameters determined from the preceding studies.

Table 4.4 Hydrology Values

Field Application	Area (hectare)	Slope (m/m)	Slope Length (m)
1. Lanoue W1	5.851	0.001	670.5
2. Lanoue W2	4.047	0.001	640.0
3. Barrette W1	4.998	0.003	342.9
4. Barrette W2	2.630	0.002	202.1
5. Doyle W1	16.714	0.003	624.1
6. Doyle W2	9.612	0.002	639.2
7. AFF Farms W1	2.801	0.001	213.3
8. AFF Farms W2	2.801	0.001	213.3
9. AFF Farms W3	2.801	0.001	213.3
10. AFF Farms W4	20.397	0.001	570.9
11. AFF Farms W5	5.099	0.001	570.9
12. AFF Farms W6	19.397	0.001	440.4

The crop parameter group included the leaf area index, depth of root zone, surface roughness and winter cover factor parameters based on cropping practice observations recorded by individual farm operators who participated in the land planing studies. For each field, numerical values were interpreted from the observed crop type. Table 4.5 gives the recorded crop type, for the period 890331 to 900917, upon which parametric values were based. Values selected for crop parameters are summarized in Appendix C.

Table 4.5 Observed Crop Type

Field Application	Crop 1989	Crop 1990
1. Lanoue W1	tomatoes	wheat
2. Lanoue W2	tomatoes	wheat
3. Barrette W1	corn	soybeans
4. Barrette W2	corn	soybeans
5. Doyle W1	soybeans	soybeans
6. Doyle W2	wheat	soybeans
7. AFF Farms W1	crop failure	wheat
8. AFF Farms W2	crop failure	wheat
9. AFF Farms W3	crop failure	wheat
10. AFF Farms W4	soybeans	wheat
11. AFF Farms W5	soybeans	wheat
12. AFF Farms W6	soybeans	wheat

The soil parameter group consisted of the effective saturated conductivity, effective capillary tension, porosity, fraction of the plant-available water storage filled when simulation begins, depth of surface soil, immobile water content, portion of plant-available water storage filled at field capacity and the soil evaporation parameters. These were based on observations recorded from soil pit surveys and textural classifications by Can-Ag staff.

For each field, numerical values for all parameters, except surface soil depth, were interpreted primarily from the textural classifications. Numerical values for the surface soil depth parameter were taken from the soil pit survey. Table 4.6 gives the soil series identified in each field, and from which textural classifications were assigned. Values selected for the soil parameters used in the parametric analysis are given in Appendix D.

Table 4.6 Observed Soil Series

Field Application	Soil Series
1. Lanoue W1	Brookston[1]
2. Lanoue W2	Brookston
3. Barrette W1	Brookston
4. Barrette W2	Brookston
5. Doyle W1	Brookston
6. Doyle W2	Brookston
7. AFF Farms W1	Toledo[2]
8. AFF Farms W2	Toledo
9. AFF Farms W3	Toledo
10. AFF Farms W4	Toledo
11. AFF Farms W5	Toledo
12. AFF Farms W6	Toledo

[1] Brookston has between 29-47% clay

[2] Toledo has between 50-68% clay

The preceding field parameters were applied, during parametric analysis, to continuous modelling of field conditions for all of the fields in the land planing studies during the period May'89 to September'90. For this instance of continuous modelling, the modified version of the CREAMS hydrologic component predicted episodes of overland flow which are listed with observed episodes of overland flow in Table 4.7. An episode is a day on which overland runoff occurs (either observed or calculated).

Table 4.7 Predicted and Observed Episodes From Parametric Analysis

Field Application	Observed Episodes (a)	Predicted Episodes (b)
1. Lanoue W1	12	4
2. Lanoue W2	11	4
3. Barrette W1	15	5
4. Barrette W2	11	4
5. Doyle W1	2	1
6. Doyle W2	12	4
7. AFF Farms W1	10	5
8. AFF Farms W2	8	5
9. AFF Farms W3	8	5
10.AFF Farms W4	15	8
11.AFF Farms W5	10	5
12.AFF Farms W6	11	4

(ii) Sensitivity Analysis

The modified version of the CREAMS hydrologic component was applied to AFF Farms Weir#4 field for the period from Julian day 90, 1989 to Julian day 365, 1989, and for this application, the same parameters, which were described in the parametric analysis, were applied. Table 4.8 gives the number of predicted episodes of overland flow for the range in numerical values of the precipitation parameter.

Table 4.9 gives the number of predicted episodes of overland flow in relation to the selected range in numerical values for the parameters other than precipitation. Predictions from upper and lower limits differed by more than one episode of overland flow for only two of the seventeen model parameters. These two parameters are field surface roughness and effective saturated conductivity.

Table 4.8 Time Interval and Number of Episodes for Precipitation Parameter

Time Interval	30 Minute	15 Minute	60 Minute
Number of Episodes	4	4	4

(iii) Calibration

The modified version of the CREAMS hydrologic component was applied to each of the fields in the study area for period May'89 to September'90. The calibration factors were the two identified (i.e. surface roughness and effective

Table 4.9 Model Parameters and Number of Episodes, Sensitivity Analysis

Parameter	Representative Value	Range Upper Lower	Upper Range Episodes	Lower Range Episodes
Temperature	Table 4.2	(+10%) (-10%)	4	4
Solar Rad.	Table 4.2	(+25%) (-25%)	4	4
Field Area	20.397 ha	(+25%) (-25%)	4	4
Slope	0.001 m/m	(+100%) (0%)	4	4
Slope Length	570.9 m	(+50%) (-75%)	3	4
Leaf Area Index	Table C.2	(+25%) (-25%)	4	4
Root Depth	91.5 cm	(+50%) (-50%)	4	4
Roughness	0.040	(+388%)(-50%)	3	5
Winter Cover	1.000	(0%) (-25%)	4	4
Effective Sat. Cond.	0.102 cm/h	(+200) (-75%)	2	7
Effective Cap. Tension	50.8 cm	(+25%) (-25%)	3	4
Porosity	0.480 cm/cm	(+25%) (-25%)	4	4
Plant Avail. Water Storage at start	1.000	(0%) (-25%)	4	4
Surface Soil Depth	11.000 cm	(+50%) (-50%)	4	3
Immobile Soil Water Content	0.210 cm/cm	(+25%) (-25%)	4	3
Plant-Avail. Water Storage Filled @ F.C.	0.722 cm/cm	(+25%) (-25%)	4	4
Soil Evap. Factor	3.5 (mm/d$^{1/2}$)	(+28%) (-6%)	4	4

saturated conductivity) as having the greatest effect on the sensitivity of the model output. For each application, numerical values for the surface roughness (RMN) parameter were determined for seasonal intervals according to actual field and crop conditions. A numerical value for the effective saturated conductivity (RC) parameter was then adjusted for each field and season to best fit observed episodes of overland runoff.

Numerical input values for the surface roughness parameter (RMN), seasonal interval, and corresponding cropping practice are given in Figures 4.1 through 4.12. Also Figures 4.1 through 4.12 give the corresponding calibrated values for the effective saturated conductivity, which result from matching predicted to observed episodes of overland flow, along with the number of predicted and observed episodes of overland flow for each seasonal interval. Table 4.10 gives a summary of the predicted episodes of overland flow related to observed episodes of overland flow.

During calibration, application of the hydrologic component of CREAMS resulted in prediction of some episodes of overland flow for which no occurrence was recorded by the field instruments. These are referred to as unobserved predictions, and Figures 4.1 through 4.12 give the number of such events for each seasonal interval. A summary of the number of unobserved predictions for each field is given in Table 4.10. Also in Table 4.10, reliability is defined according to the assumption that the unobserved predictions did not occur (Joy, pers. comm.).

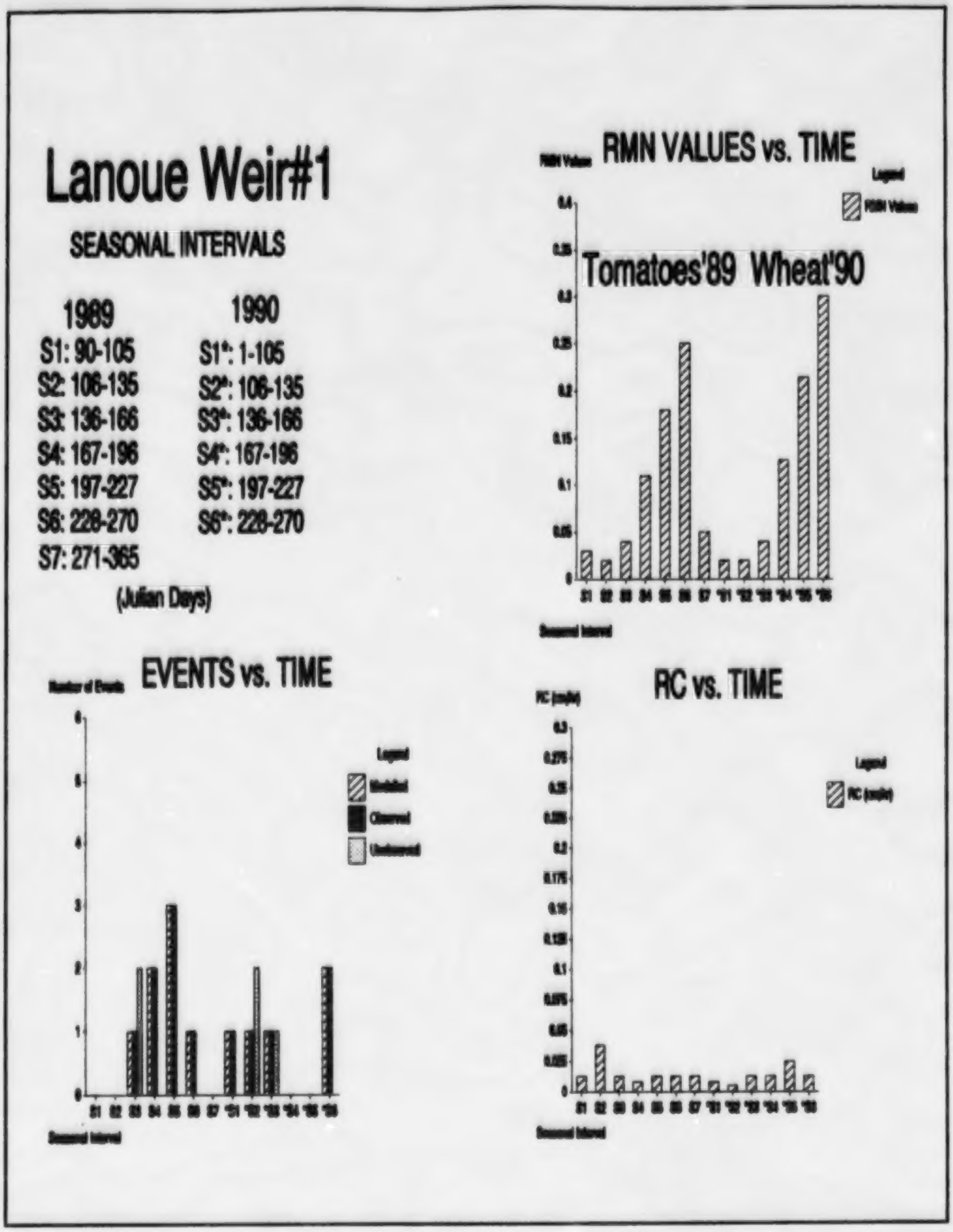


Figure 4.1 Predicted, Unobserved Predicted and Observed Episodes: Lanoue W1

RMN = surface roughness parameter
RC = effective saturated conductivity

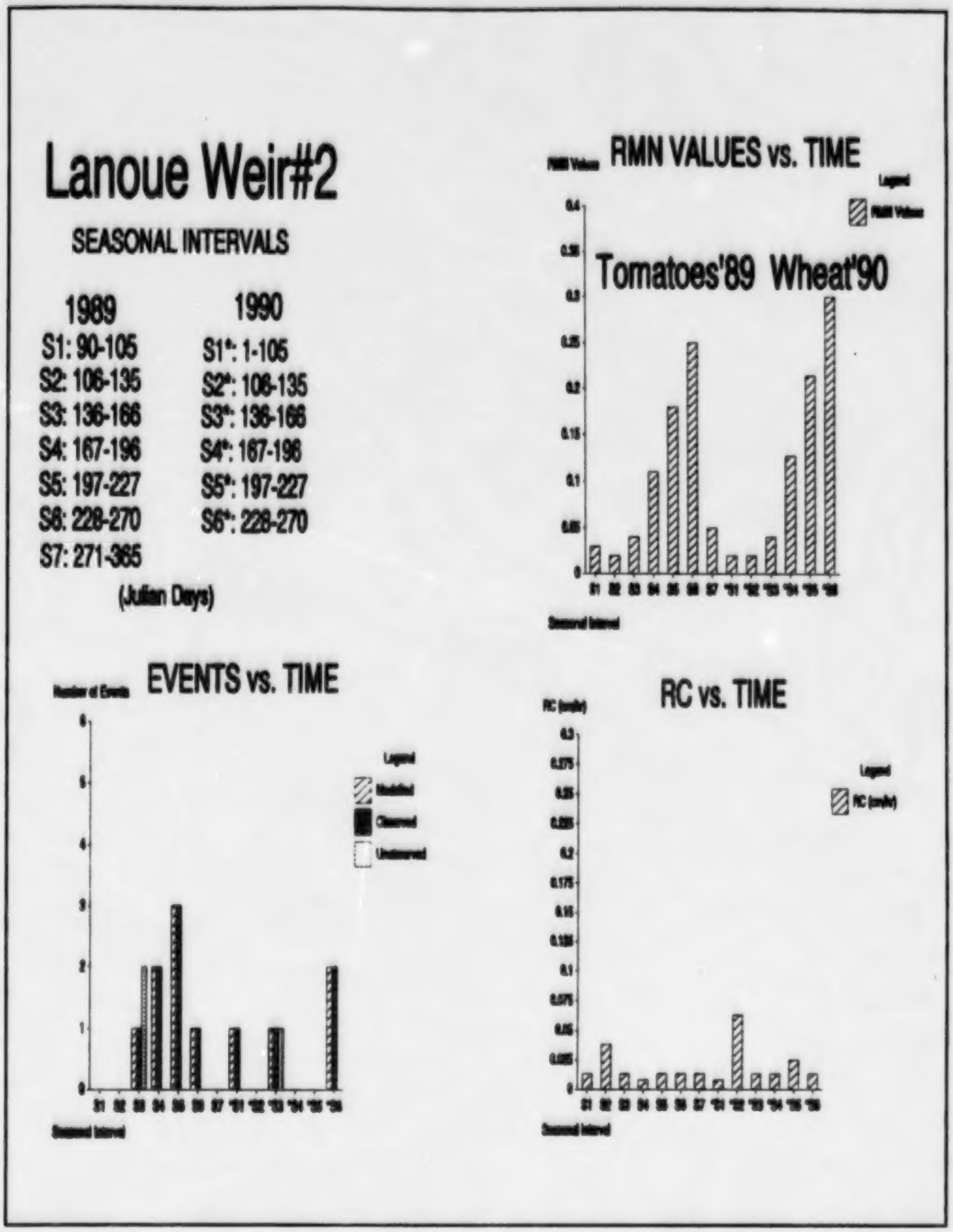


Figure 4.2 Predicted, Unobserved Predicted and Observed Episodes: Lanoue W2

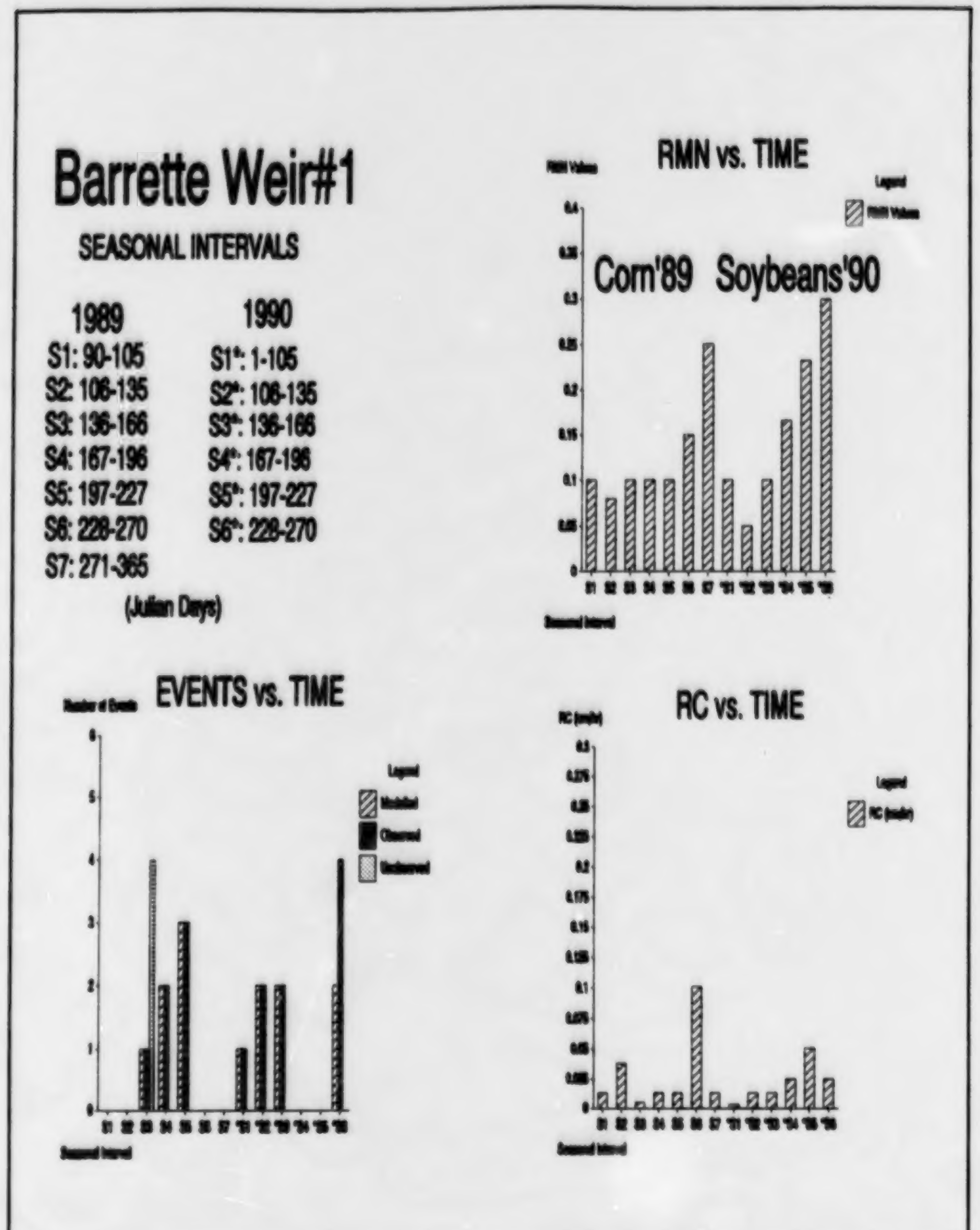


Figure 4.3 Predicted, Unobserved Predicted and Observed Episodes: Barrette W1

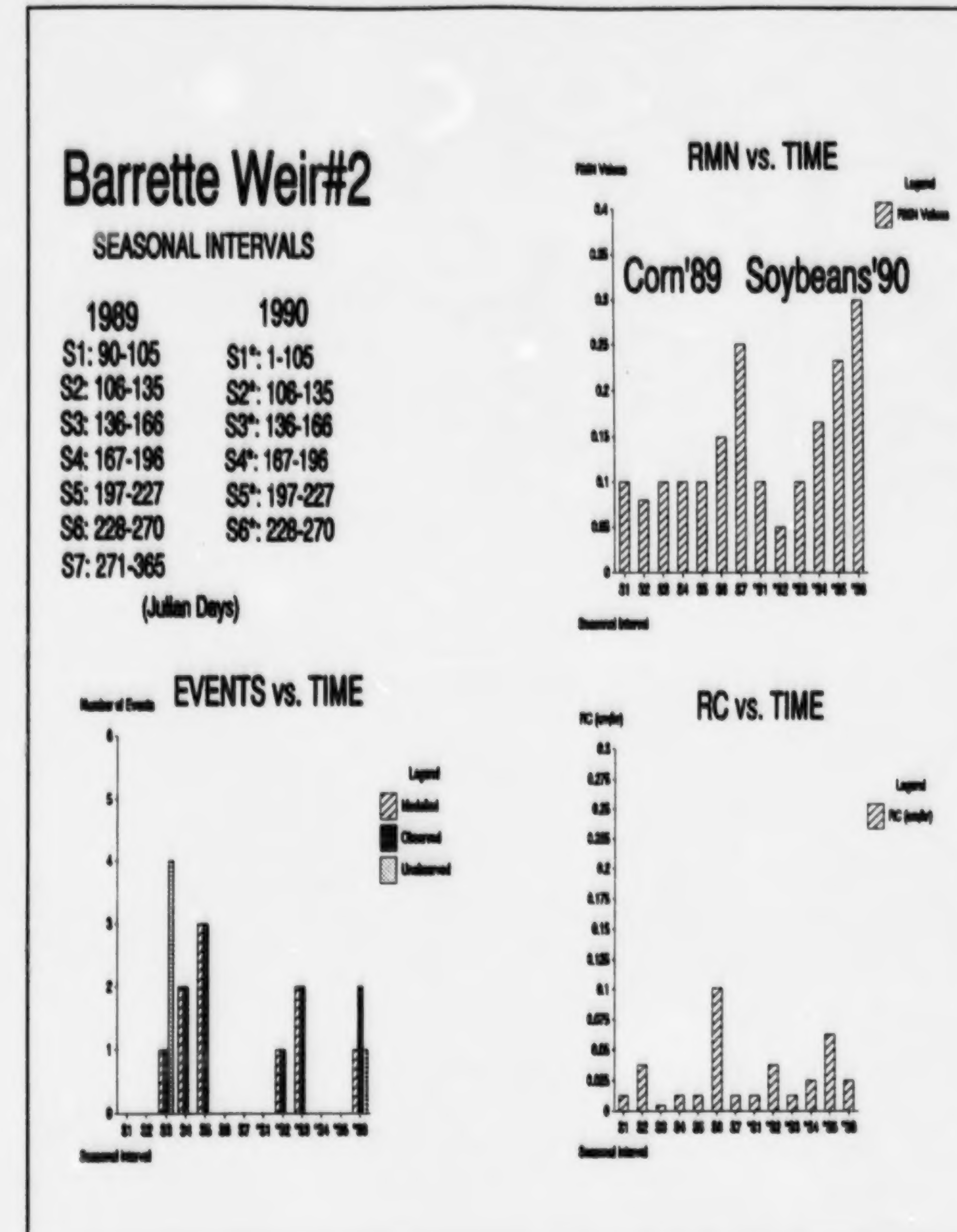


Figure 4.4 Predicted, Unobserved Predicted and Observed Episodes: Barrette W2

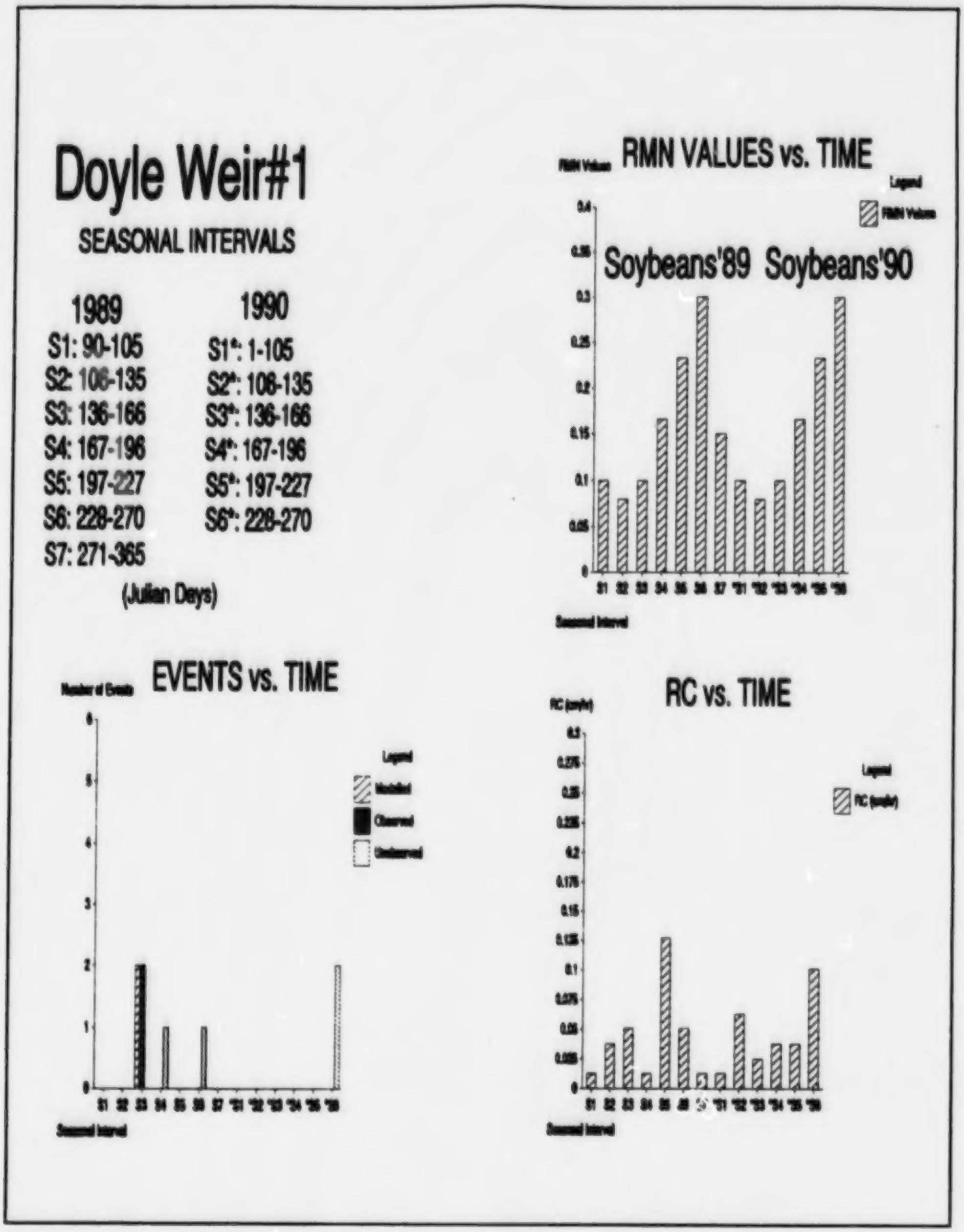


Figure 4.5 Predicted, Unobserved Predicted and Observed Episodes: Doyle W1

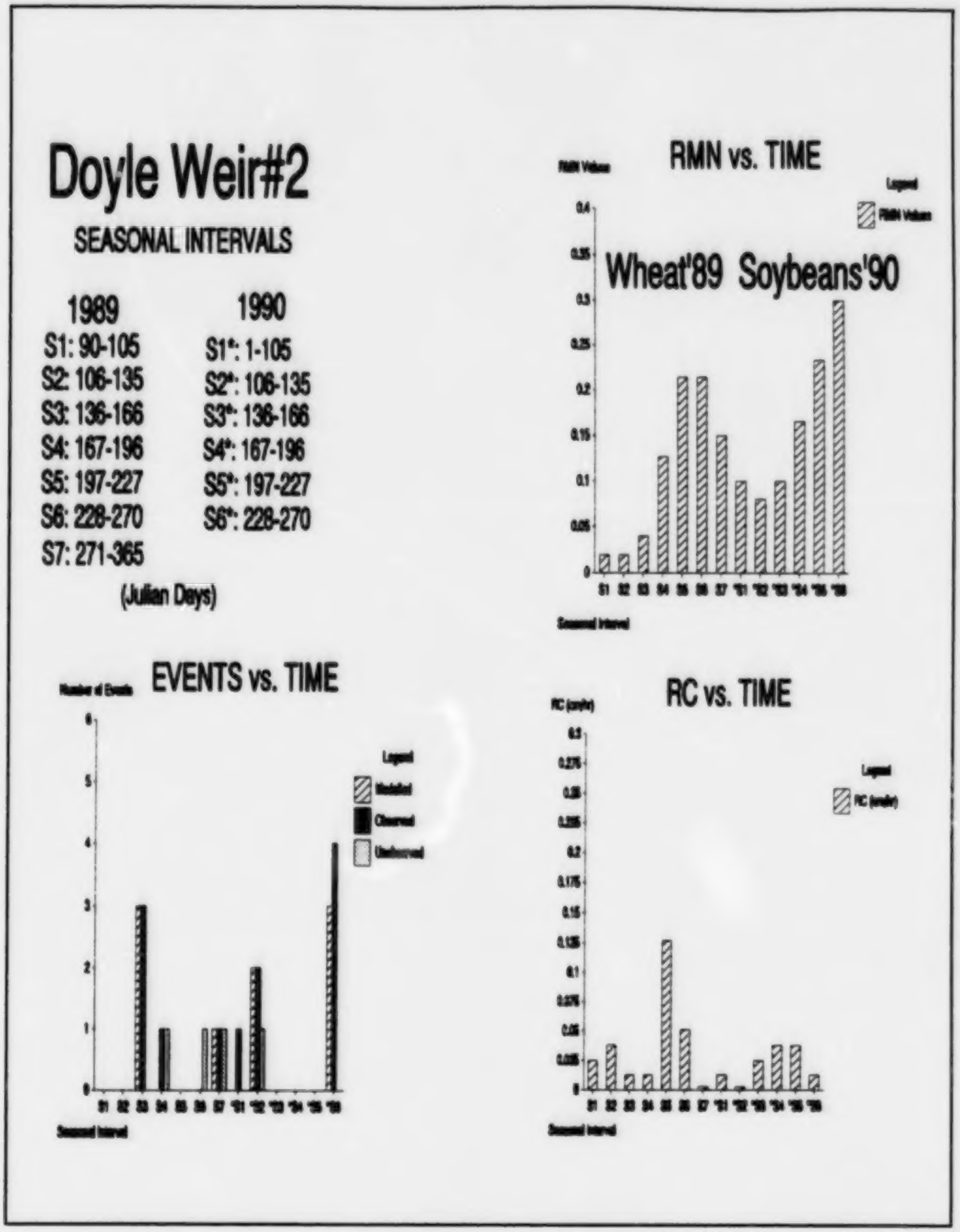


Figure 4.6 Predicted, Unobserved Predicted and Observed Episodes: Doyle W2

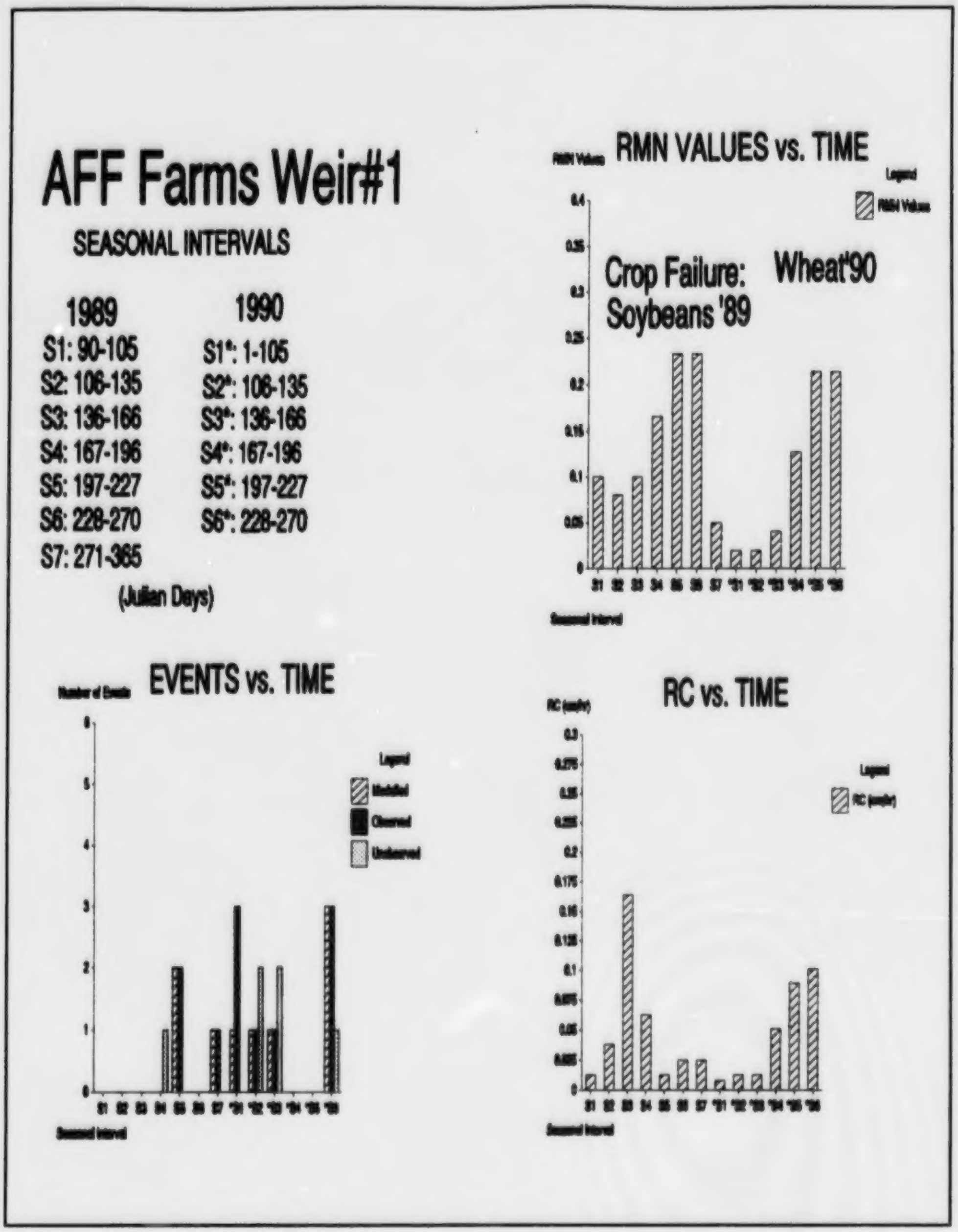
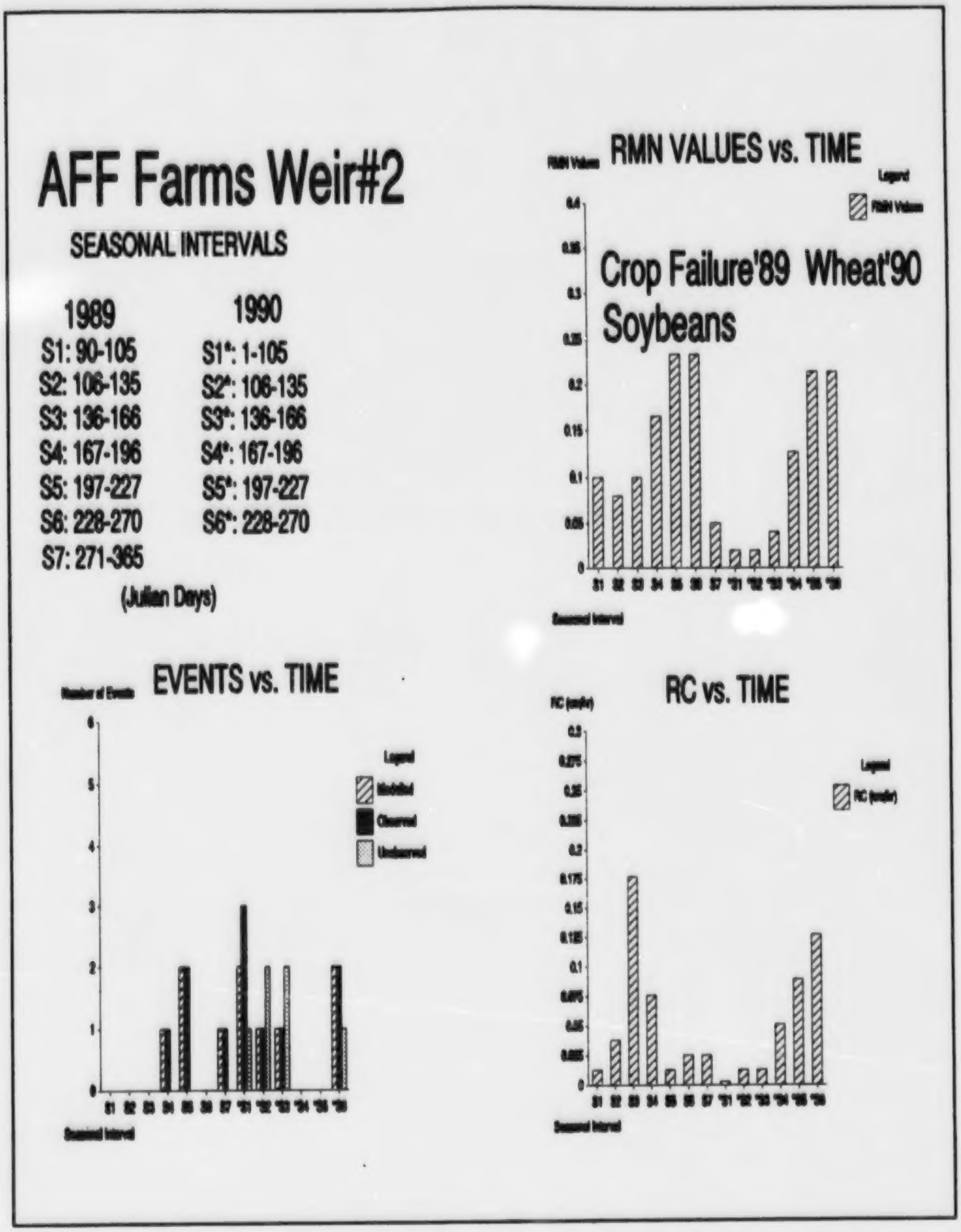


Figure 4.7 Predicted , Unobserved Predicted and Observed Episodes: AFF Farms W1



<u>Figure 4.8</u> **Predicted, Unobserved Predicted and Observed Episodes: AFF Farms W2**

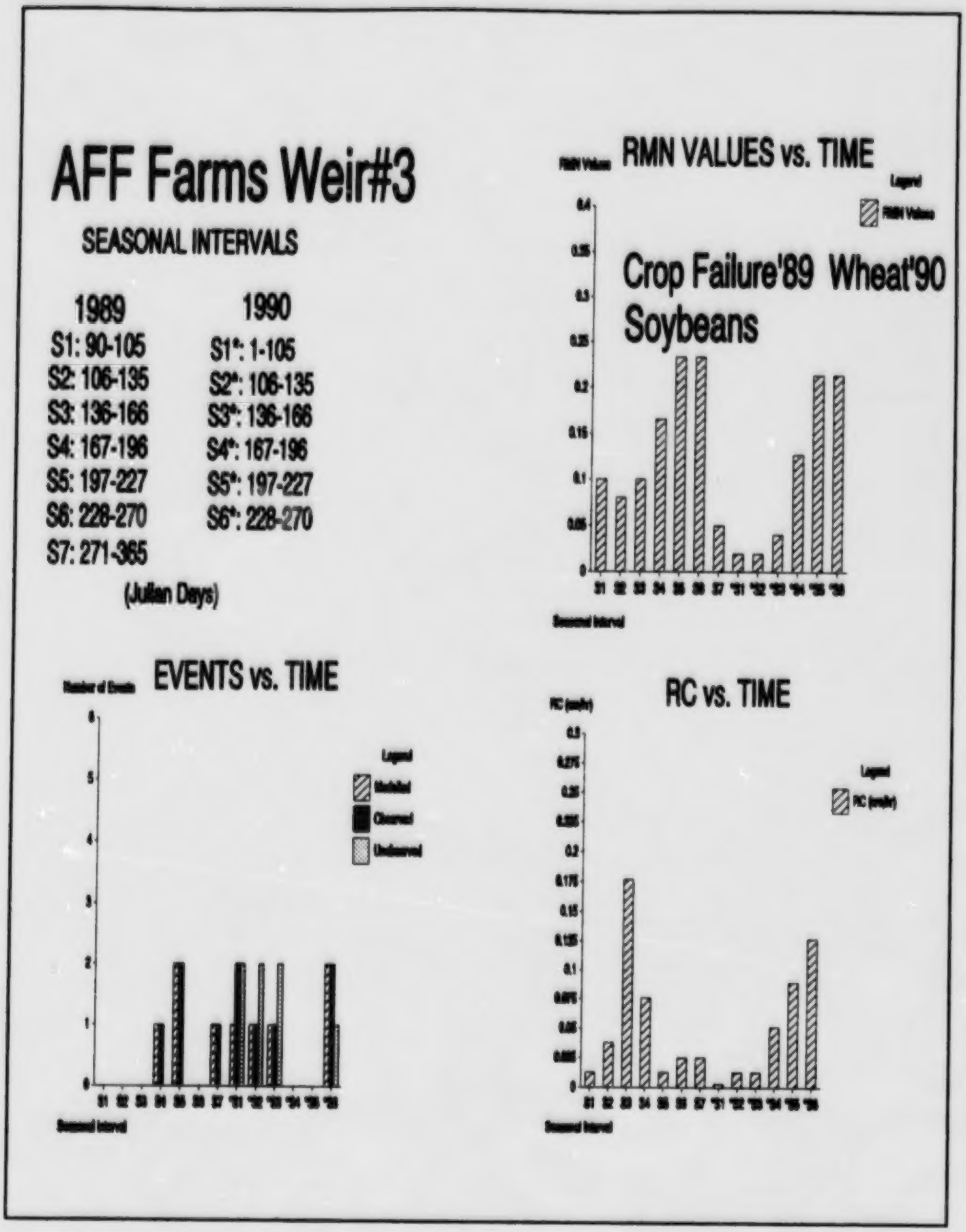


Figure 4.9 Predicted, Unobserved Predicted and Observed Episodes: AFF Farms W3

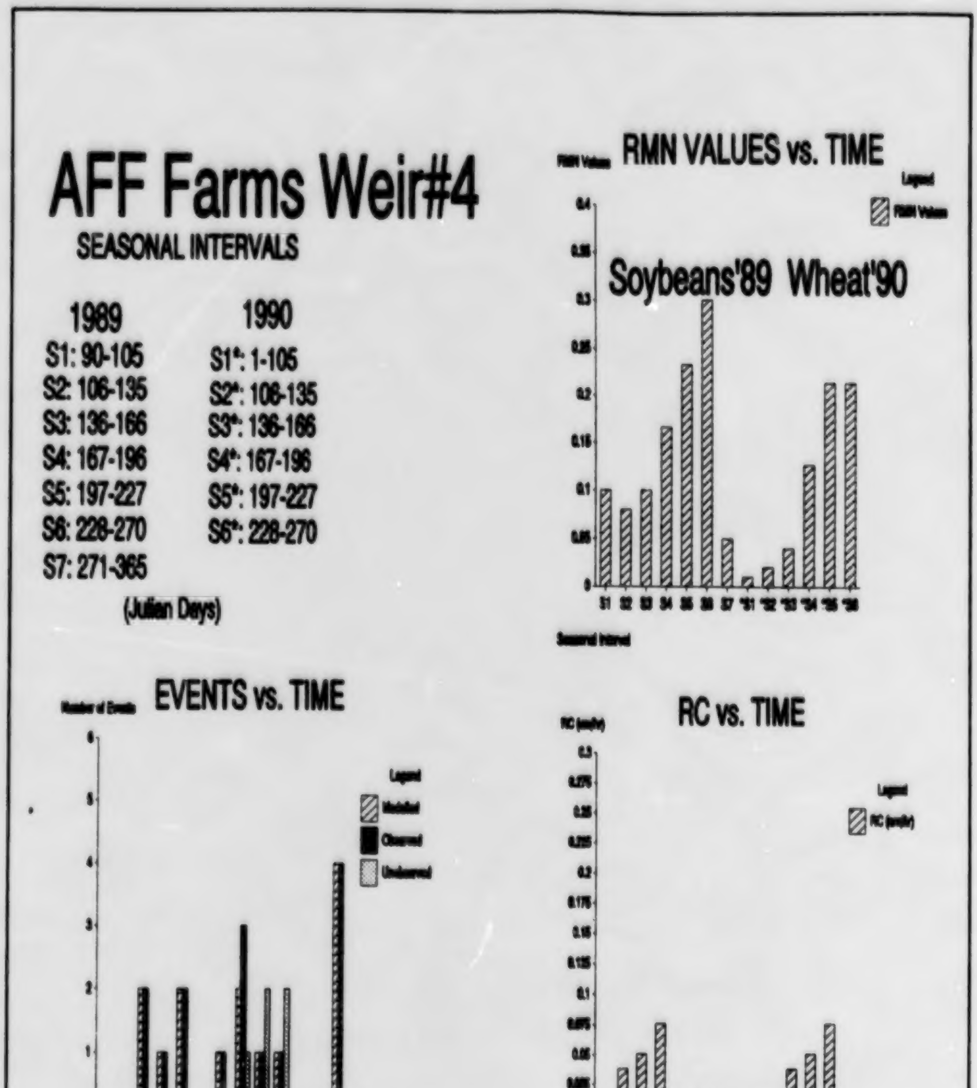


Figure 4.10 Predicted, Unobserved Predicted and Observed Episodes: AFF Farms W4

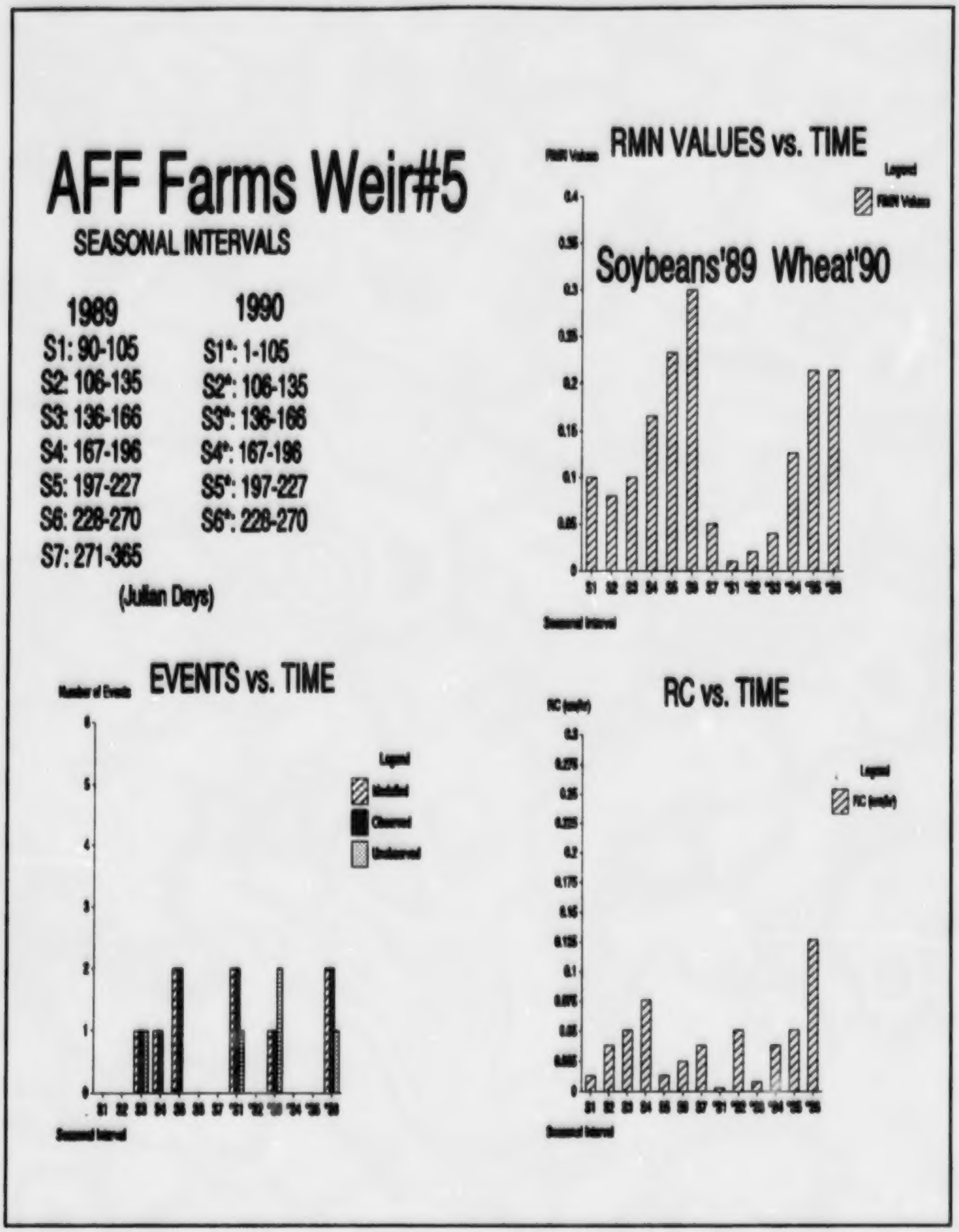


Figure 4.11 Predicted, Unobserved Predicted and Observed Episodes: AFF Farms W5

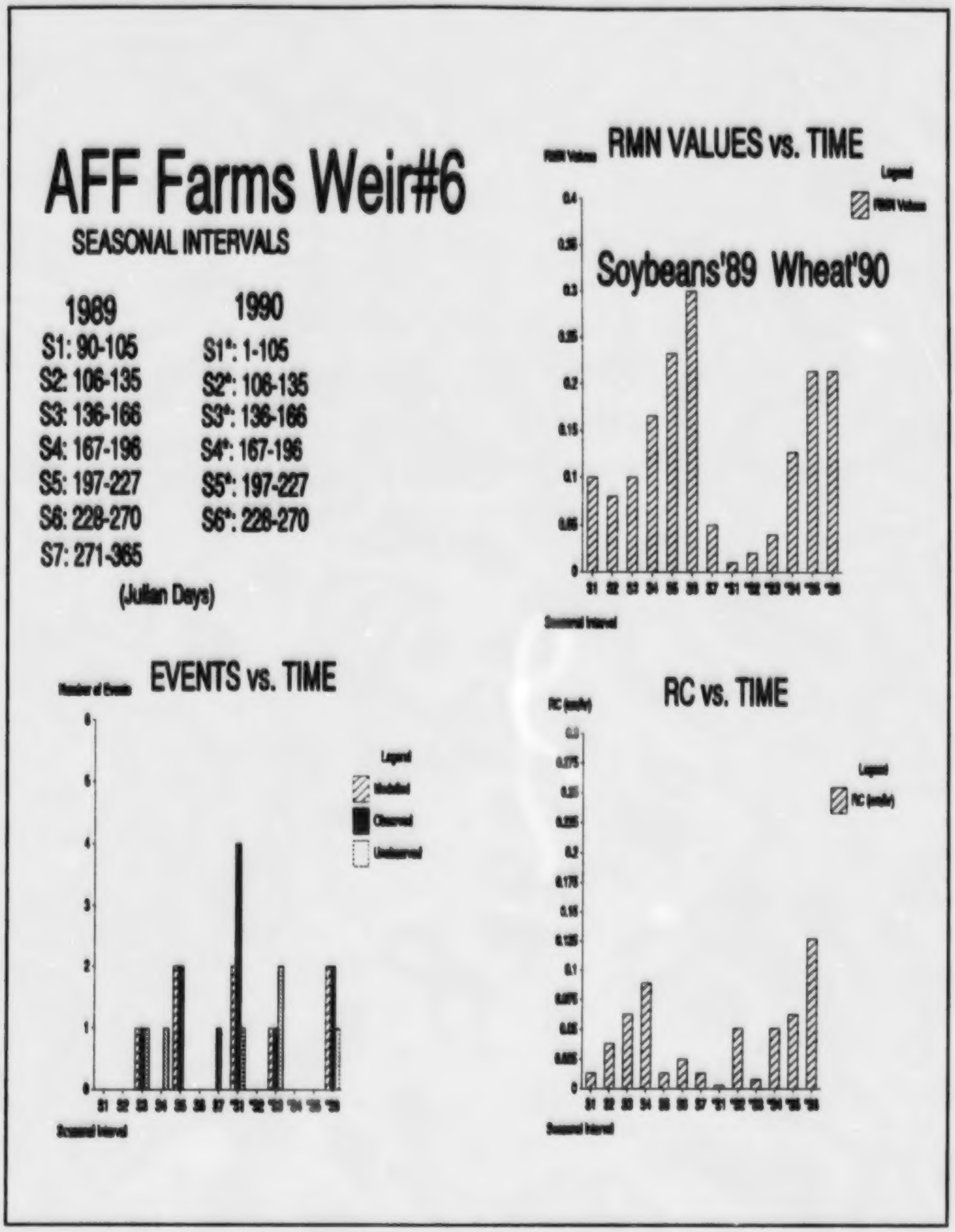


Figure 4.12 Predicted, Unobserved Predicted and Observed Episodes: AFF Farms W6

Table 4.10 Summary of Predicted, Unobserved Predicted and Observed Episodes

Field Application	Observed Episodes (a)	Predicted Episodes (b)	Unobserved Predictions (c)	Model Reliability*
Lanoue W1	12	12	5	0.71
Lanoue W2	11	11	3	0.78
Barrette W1	15	13	4	0.65
Barrette W2	11	10	5	0.60
Doyle W1	2	2	4	0.33
Doyle W2	12	9	4	0.46
AFF Farms W1	11	9	6	0.46
AFF Farms W2	11	10	6	0.56
AFF Farms W3	10	9	7	0.50
AFF Farms W4	15	14	5	0.69
AFF Farms W5	9	9	5	0.64
AFF Farms W6	11	8	6	0.43

Model Reliability* = 1 - (abs(a-b))/(b+c) - c/(b+c)

(iv) Phosphorus Predictions

The modified CREAMS hydrologic component, along with the erosion and chemicals components, was applied to Lanoue Weir#1 field for the period from May'89 to September'90. For this application, there were 12 correct predictions of episodes of overland flow, 12 concurrent phosphorus predictions and 4 runoff samples analyzed for phosphorus content. The results are given in Tables 4.11 and 4.12. In Table 4.11 predicted total phosphorus concentration was the sum of predicted phosphorus with sediment and predicted phosphorus in runoff.

Predicted phosphorus concentration in sediment was attained by dividing the model's predicted phosphorus quantity(kg/ha) by the depth of predicted runoff(cm) and multiplying by 10. Predicted phosphorus in runoff was given in the model output as ppm (mg/L). Observed total phosphorus concentration was the average of sample concentrations analyzed for the specific episode of overland flow. Table 4.12 gives the predicted concentrations of dissolved phosphorus and observed concentrations of filtered reactive phosphorus.

Table 4.11 Predicted and Observed Phosphorus Production

Date (Julian Day and Year)	Predicted Total Phosphorus Concentration (mg/L)	Observed Total Phosphorus Concentration (mg/L)
163 1989	0.29	not available
170 1989	0.32	not available
177 1989	0.29	not available
200 1989	0.29	not available
201 1989	0.35	1.3
207 1989	0.29	0.85
240 1989	0.31	not available
99 1990	0.29	not available
110 1990	0.29	not available
136 1990	0.29	not available
249 1990	0.32	0.53
257 1990	0.33	0.56

Table 4.12 Predicted and Observed Phosphorus Production

Date (Julian Day and Year)	Predicted Dissolved Phosphorus Concentration (mg/L)	Observed Filtered Reactive Phosphorus Concentration (mg/L)
163 1989	0.29	not available
170 1989	0.32	not available
177 1989	0.29	not available
200 1989	0.29	not available
201 1989	0.35	not available
207 1989	0.29	0.40
240 1989	0.31	not available
99 1990	0.29	not available
110 1990	0.29	not available
136 1990	0.29	not available
249 1990	0.32	0.47
257 1990	0.33	0.56

5. EVALUATION OF THE RESULTS

The modified version of the CREAMS hydrologic component was used to determine empirical values for field parameters that affect overland flow episodes. If the component was successful in determining these empirical values, the CREAMS erosion and chemical components would then used to represent the circumstances under which phosphorus transport might occur. The criteria used in determining the feasibility of representing the circumstances were listed in Chapter 2, and the results of the procedure for determining empirical values were given Chapter 4. Determination of empirical values was divided into four parts: parametric analysis, sensitivity analysis, calibration and phosphorus predictions. Combined, these parts led to the determination of empirical values which affected overland flow and, consequently, related phosphorus transport.

(a) Parametric Analysis

Results from the parametric analysis appear in Table 4.6 and show that the use of representative values determined for the parameters in the modified hydrologic component resulted in prediction of some episodes of overland flow. Neither the number of predicted episodes of overland flow nor the range in values for parameters that contributed to the predictions were important in this part. Prediction of episodes of overland flow showed that the modified component could represent the circumstances continuously over the study period.

(b) Sensitivity Analysis

Tables 4.7 and 4.8 show that the range in values, determined for all of the parameters, resulted in prediction of some episodes of overland flow. The number of predicted episodes of overland flow was not important since prediction of some episodes of overland flow showed that the hydrologic component could represent the selected range in values for all of the parameters at the field scale.

In addition, the results in Table 4.7 and 4.8 showed that predictions from the upper and lower limits differed by more than one flow episode for only two of the seventeen parameters. These two parameters were the field surface roughness and effective saturated conductivity and produced the greatest variation in the number of episodes of overland flow because both parameters are part of the modelling structure which is used to predict overland flow. The effective surface roughness parameter is used in the calculation of storage in the profile of overland flow film, and the effective saturated conductivity is used in the calculation of infiltration. The model predicts overland flow when the amount of precipitation exceeds the amount of water infiltrating and the amount of detention storage. Thus, the surface roughness parameter and effective saturated conductivity parameter were used to successfully calibrate the modified hydrologic component as proposed in Chapters 3 and 4.

(c) Calibration

Calibration determined empirical values using the modified hydrologic component with respect to the three criteria: correct predictions of individual

observed surface episodes of overland flow, application across seasons and application across fields.

(i) <u>Individual Predictions</u>

Table 4.9, based upon Figures 4.1 through 4.12, shows that the application of the modified hydrologic component to the fields in the study area resulted in the prediction of 116 of 130 observed episodes of overland flow. With the exception of AFF Farms Weir #1 & #6 field and Doyle Weir #1 & #2 field, reliability of application of the modified hydrologic component to the fields in the study was 0.50 or higher. AFF Farms Weir #1 & #6 field and Doyle Weir #1 & #2 field had reliability values above 0.30 which also shows a good agreement between predicted and observed surface episodes of overland flow.

Table 4.9 and Figures 4.1 through 4.12 also show that the application of the modified hydrologic component to the study fields predicted 60 episodes of overland flow that were not observed in the field. However, 22 of the unobserved predictions occurred during periods of known recording failures. These failures occurred in the recording instruments for all of the study fields until Julian day 155 during 1989. Up to this point, improvements in the recording instruments were necessary to assure recording of minor flows during episodes of overland flow. Subsequent failures occurred from Julian day 334 during 1989 to Julian 90 during 1990 for all of the fields, due to freezing problems, and failures occurred throughout the study period for Doyle Weir #1 field, due to weir washouts and recording instrument problems. A summary of the 38 unobserved predictions that are not

instrument problems. A summary of the 38 unobserved predictions that are not explained by known failures is given in Table 5.1.

Table 5.1 Unobserved Predictions Between 1989-1990

Field Application	**Unobserved Prediction** (a)	**Installation Failure** (b)	**Failure Due To 1)Freezing 2)Washout 3)Instrument** (c)	**Result** (a-b-c)
Lanoue W1	5	2	0	3
Lanoue W2	3	2	0	1
Barrette W1	4	3	0	1
Barrette W2	5	3	0	2
Doyle W1	4	0	4	0
Doyle W2	4	0	0	4
AFF Farms W1	6	0	0	6
AFF Farms W2	6	0	1	5
AFF Farms W3	7	0	2	5
AFF Farms W4	5	0	1	4
AFF Farms W5	5	1	1	3
AFF Farms W6	6	1	1	4
Total	60	12	10	38

(ii) Predictions Across Seasons within Fields

Figures 4.1 through 4.12 show the distribution of predicted, unobserved predicted and observed surface episodes of overland flow across seasons within

a field. Based upon Figures 4.1 through 4.12, Tables 5.2 and 5.3 were prepared to present a summary of correct predictions across seasonal intervals within each of the fields considered. In Tables 5.2 and 5.3, the end day of each seasonal interval is given by month and calendar date. The results show those seasons for which correct predictions were made within each field considered.

Table 5.2 Distribution of Correct Predictions for 1989

Field Application	Crop	S1 0415	S2 0515	S3 0615	S4 0715	S5 0815	S6 0927	S7 1231
Lanoue W1	tomato	0	0	1	2	3	1	0
Lanoue W2	tomato	0	0	1	2	3	1	0
Barrette W1	corn	0	0	1	2	3	0	0
Barrette W2	corn	0	0	1	2	3	0	0
Doyle W1	soybeans	0	0	2	0	0	0	0
Doyle W2	wheat	0	0	3	0	0	0	1
AFF Farms W1	crop failure	0	0	0	0	2	0	1
AFF Farms W2	crop failure	0	0	0	1	2	0	1
AFF Farms W3	crop failure	0	0	0	1	2	0	1
AFF Farms W4	soybeans	0	0	2	1	2	0	1
AFF Farms W5	soybeans	0	0	1	1	2	0	0
AFF Farms W6	soybeans	0	0	1	0	2	0	0

Table 5.3 Distribution of Correct Predictions for 1990

Field Application	Crop	*S1 0415	*S2 0515	*S3 0615	*S4 0715	*S5 0815	*S6 0927
Lanoue W1	wheat	1	1	1	0	0	2
Lanoue W2	wheat	1	0	1	0	0	2
Barrette W1	soybeans	1	2	2	0	0	2
Barrette W2	soybeans	0	1	2	0	0	1
Doyle W1	soybeans	0	0	0	0	0	0
Doyle W2	soybeans	0	2	0	0	0	3
AFF Farms W1	wheat	1	1	1	0	0	3
AFF Farms W2	wheat	2	1	1	0	0	2
AFF Farms W3	wheat	1	1	1	0	0	2
AFF Farms W4	wheat	2	1	1	0	0	4
AFF Farms W5	wheat	2	0	1	0	0	2
AFF Farms W6	wheat	2	0	1	0	0	2

Tables 5.2 and 5.3 show that correct predictions were made across seasonal intervals for a broad range of field and crop conditions within each field. However, for the Doyle Weir #1 field, there were only two correct predictions across all of the seasons. During this time period, weir washouts and recording instrument problems prevented any record of observed surface episodes of overland flow at this location.

The last column in Table 5.1 gives the number of unobserved predictions of episodes of overland flow that are not explained after known failures of runoff recording system have been considered. Tables 5.4 and 5.5 were prepared to show the distribution of unexplained unobserved predictions across seasonal

intervals within each field. The results show those seasons for which unexplained unobserved predictions were made within each field considered.

Table 5.4 Distribution of Unexplained Unobserved Predictions: 1989

Field Application	Crop	S1 0415	S2 0515	S3 0615	S4 0715	S5 0815	S6 0927	S7 1231
Lanoue W1	tomato	0	0	0	0	0	0	0
Lanoue W2	tomato	0	0	0	0	0	0	0
Barrette W1	corn	0	0	1	0	0	0	0
Barrette W2	corn	0	0	1	0	0	0	0
Doyle W1	soybeans	0	0	0	0	0	0	0
Doyle W2	wheat	0	0	0	1	0	1	1
AFF Farms W1	crop failure	0	0	0	1	0	0	0
AFF Farms W2	crop failure	0	0	0	0	0	0	0
AFF Farms W3	crop failure	0	0	0	0	0	0	0
AFF Farms W4	soybeans	0	0	0	0	0	0	0
AFF Farms W5	soybeans	0	0	0	0	0	0	0
AFF Farms W6	soybeans	0	0	0	1	0	0	0

From Tables 5.4 and 5.5, a total of 38 unexplained unobserved predictions were made across seasons for a broad range of field and crop conditions. Of the unexplained unobserved predictions, 27 out of the 38 were made during modelling of the six AFF Farms fields.

Table 5.5 Distribution of Unexplained Unobserved Predictions: 1990

Field Application	Crop	*S1 0415	*S2 0515	*S3 0615	*S4 0715	*S5 0815	*S6 0927
Lanoue W1	wheat	0	2	1	0	0	0
Lanoue W2	wheat	0	0	1	0	0	0
Barrette W1	soybeans	0	0	0	0	0	0
Barrette W2	soybeans	0	0	0	0	0	1
Doyle W1	soybeans	0	0	0	0	0	0
Doyle W2	soybeans	0	1	0	0	0	0
AFF Farms W1	wheat	0	2	2	0	0	1
AFF Farms W2	wheat	0	2	2	0	0	1
AFF Farms W3	wheat	0	2	2	0	0	1
AFF Farms W4	wheat	0	2	2	0	0	0
AFF Farms W5	wheat	0	0	2	0	0	1
AFF Farms W6	wheat	0	0	2	0	0	1

The observed episodes of overland flow that were not predicted are summarized in Tables 5.6 and 5.7. Tables 5.6 and 5.7 show their distribution across seasonal intervals within each field considered. From Tables 5.6 and 5.7, only 14 out of 130 observed episodes were not predicted across seasons for a broad range of field crop conditions for all study fields. There were 8 of the 14 observed episodes not predicted that occurred during modelling of the six AFF Farms fields.

Table 5.6 Distribution of Observed Episodes Not Predicted for 1989

Field Application	Crop	S1 0415	S2 0515	S3 0615	S4 0715	S5 0815	S6 0927	S7 1231
Lanoue W1	tomato	0	0	0	0	0	0	0
Lanoue W2	tomato	0	0	0	0	0	0	0
Barrette W1	corn	0	0	0	0	0	0	0
Barrette W2	corn	0	0	0	0	0	0	0
Doyle W1	soybeans	0	0	0	0	0	0	0
Doyle W2	wheat	0	0	0	1	0	0	0
AFF Farms W1	crop failure	0	0	0	0	0	0	0
AFF Farms W2	crop failure	0	0	0	0	0	0	0
AFF Farms W3	crop failure	0	0	0	0	0	0	0
AFF Farms W4	soybeans	0	0	0	0	0	0	0
AFF Farms W5	soybeans	0	0	0	0	0	0	0
AFF Farms W6	soybeans	0	0	0	0	0	0	1

Table 5.7 Distribution of Observed Episodes Not Predicted for 1990

Field Application	Crop	*S1 0415	*S2 0515	*S3 0615	*S4 0715	*S5 0815	*S6 00927
Lanoue W1	wheat	0	0	0	0	0	0
Lanoue W2	wheat	0	0	0	0	0	0
Barrette W1	soybeans	0	0	0	0	0	2
Barrette W2	soybeans	0	0	0	0	0	1
Doyle W1	soybeans	0	0	0	0	0	0
Doyle W2	soybeans	1	0	0	0	0	1
AFF Farms W1	wheat	2	0	0	0	0	0
AFF Farms W2	wheat	1	0	0	0	0	0
AFF Farms W3	wheat	1	0	0	0	0	0
AFF Farms W4	wheat	1	0	0	0	0	0
AFF Farms W5	wheat	0	0	0	0	0	0
AFF Farms W6	wheat	2	0	0	0	0	0

Figures 4.1 through 4.12 also show the distribution of effective saturated conductivity values which were calibrated across seasons within a field. Generally, these values varied substantially across seasons for most applications to study fields. The conductivity values had a maximum range of 0.003 cm/h to 0.177 cm/h for the application of the modified hydrologic component across seasons to the AFF Farms Weir #2 and #3 fields. The conductivity values had a minimum range of 0.008 cm/h to 0.025 cm/h for the application to Lanoue Weir #1 field.

Differences in ranges may be related to the differences in raingauge proximity to fields (and hence, accuracy of rainfall inputs) or in soil series. Table 4.1 shows that the Lanoue site is 0.8km from a raingauge and the AFF Farms fields

are 18.8km from a raingauge. Table 4.5 shows that the Lanoue fields have a Brookston soil and the AFF Farms fields have a Toledo soil.

(iii) Predictions Across Fields within Seasons

Tables 5.2 and 5.3 show the distribution of correct predictions across fields within each seasonal interval considered. The results show those fields for which correct predictions were made within each seasonal interval. From Tables 5.2 and 5.3, within each seasonal interval modelled, correct predictions were made across fields for a wide range of field and crop conditions.

The distribution of unexplained unobserved predictions across fields within each of the seasonal intervals considered is given in Tables 5.4 and 5.5. The results show those seasons during which unexplained unobserved episodes of overland flow were predicted within individual fields. From Tables 5.4 and 5.5, modelling resulted in a total of 38 unexplained unobserved predictions of which 25 occurred during the *S2 and *S3 seasonal intervals of 1990.

Tables 5.6 and 5.7 show the distribution of observed episodes of overland flow that were not predicted during calibration. There were 14 observed drainage events that were not predicted, 8 of which occurred across a range of field conditions during the seasonal interval *S1, 1990 (Jan. 1, 1990 to Apr. 15, 1990).

Figures 4.1 through 4.12 show the distribution of the effective saturated conductivity, which were calibrated, across fields within a season. Generally, these values varied substantially for applications to seasons across fields. The conductivity values had a maximum range of 0.013 cm/h to 0.127 cm/h during the application of the modified hydrologic component across fields in the *S6 seasonal

interval. Conductivity values were the same for all fields during the application to the S2 seasonal interval.

The calibrated effective saturated conductivity values displayed in Figures 4.1 through 4.12 are tabulated in Appendix E. Average values for the effective saturated conductivity for the fields with Brookston soils and for the fields with Toledo soils are given in Table 5.8.

Table 5.8 Distribution Over Seasons of Calibrated Conductivity(cm/h)

Season End Date	Brookston 1989	Brookston 1990	Toledo 1989	Toledo 1990
S1 0415	0.15	0.10	0.13	0.04
S2 0515	0.38	0.31	0.38	0.25
S3 0615	0.23	0.17	1.14	0.11
S4 0715	0.11	0.25	0.76	0.47
S5 0815	0.51	0.40	0.13	0.72
S6 0927	0.55	0.32	0.23	1.14
S7 1231	0.11	-	0.23	-
Average "Cracking" Season (S3, S4, S5, S6)	0.35 (s.d. 0.21)	0.29 (s.d. 0.11)	0.57 (s.d. 0.47)	0.61 (s.d. 0.43)
Average "Non Cracking" Season (S1, S2, S7)	0.21 (s.d. 0.15)	0.21 (s.d. 0.15)	0.25 (s.d. 0.13)	0.15 (s.d. 0.15)

s.d. = standard deviation

The average values of effective saturated conductivity for the Brookston soils are quite consistent between 1989 and 1990. In both years values during the "growing" or "cracking" period from May through September were about 1.5 times the "dormant" period values. For the Toledo soils the average effective saturated conductivities were more variable between years in both the "cracking" and the "non cracking" period with the cracking period values 2 to 3 times the dormant seasonal values. The highest effective saturated conductivity values for Toledo soils occurred in the early growing period in 1989 and later in 1990. This may be due to differences in sequence and amounts of rain and hence in cracking. The distributions of rain amounts for Brookston and Toledo soils over the growing seasons are given in Tables 5.9 and 5.10. Table 5.10 shows that in 1990 the Toledo soils had 136mm (73 + 63) of rain for the early part of the "cracking" season and 352mm (104 + 248) of rain for the later part of the "cracking" season. Although the same type of pattern is not shown for 1989, the difference in rain amount for 1990 may support the possibility that cracking of dry soil is the major determinant of growing season values of effective saturated conductivity.

Table 5.9 Distribution of Rain Amounts for Brookston Soils(mm)

Year	S3	S4	S5	S6
1989	139	50	115	94
1990	58	49	83	219

Table 5.10 Distribution of Rain Amounts for Toledo Soils(mm)

Year	S3	S4	S5	S6
1989	159	92	119	96
1990	73	63	104	248

The pattern of seasonal variation in the fitted average effective saturated conductivity of the Brookston soil is less pronounced than that for the Toledo soils. The higher value seasons of S2, S5 and S6 are those where tillage (S2) and root growth (S5, S6) might provide for mechanical formation of macropores. The pattern of effective saturated conductivity change within the year is the same for 1989 and 1990 for the Brookston soils, suggesting that rain distribution within the growing season, and its effect on cracking may not be an important factor for this soil. During a site visit in the summer of 1990, it was noted that the fields with Toledo soils had much more extensive cracks than did the fields with Brookston soils.

(d) Phosphorus Predictions

In the phosphorus predictions, use of the determined empirical values of the modified hydrologic component were tested with respect to correct predictions of observed surface episodes of overland flow and concurrent phosphorus transport. Table 4.11 shows prediction of phosphorus concentrations concurrent with each correct prediction of a surface drainage episode. These results are consistent with the rationale that correct predictions of surface episodes of overland flow led to concurrent predictions of phosphorus transport.

(e) Summary

The CREAMS model was modified to evaluate the feasibility of using the hydrologic component for continuous modelling of surface episodes of overland flow. For the interval 890331 to 900917, stepwise continuous modelling proved to be feasible based upon use of seasonal model parameters to represent the conditions under which observed surface episodes of overland flow did occur.

Model predictions were found to be sensitive to the surface roughness parameter and the effective saturated conductivity parameter. In the calibration phase values for the surface roughness parameter were determined across seasons for known crop rotations in six pairs of fields, each pair containing a planed and unplaned field. Differences between surface roughness of planed and unplaned fields were not considered. Values for effective saturated conductivity were separately determined for each season and each field by calibration.

Modelling across seasons, within an individual field, was based upon generalized seasonal trends in numerical values in the surface roughness parameter according to crop rotation. Values for the effective saturated conductivity were modelled to produce accurate model predictions. By this approach, calibration of model predictions across seasons for individual fields resulted in correct predictions of 116 out of 130 observed episodes of overland flow. The model failed to predict 14 observed episodes of overland flow, 8 of which occurred during season *S1 within the fields of AFF Farms Ltd. Thus 57 percent of the 14 observed episodes of overland flow that were not predicted, occurred within the fields of AFF Farms Ltd which include 50 percent of the total

number of fields in the study area.

Successful predictions were accompanied by prediction of 60 unobserved surface episodes of overland flow for which there is no field record. Twenty-two of these were predicted to have occurred during periods when individual field recorders were known to have failed. Eight such cases are noted in Table 5.1 for the fields of AFF Farms Ltd. These eight cases represent 36 percent of the twenty-two episodes of overland flow that might not have been recorded due to instrument failure. This result is consistent with the proposition that approximately half of the instrument failures would occur in half of the fields in the study area.

The balance of unobserved predictions (60 minus 22) are distributed between fields of the study area as shown in Tables 5.4 and 5.5. Of the total 38, 27 or 71 percent of the unobserved predictions occur for the fields of AFF Farms Ltd. This proportion of the unobserved predictions exceeds the number that would be expected to occur within 50 percent of the fields in the study area.

The distribution of calibrated effective saturated conductivity values varied substantially across seasons and across fields. Maximum range in calibrated values across seasons was during the application to AFF Farms Weir #2 and #3 and across fields was during *S6 seasonal interval. Minimum range in calibrated values across seasons was during the application to Lanoue Weir #1 field and across fields was during S2 seasonal interval. The distribution of effective saturated conductivity values calibrated for each seasonal interval is given in Tables E.1 and E.2 in Appendix E.

Average values for the effective saturated conductivity found by calibration

for the Brookston soil are fairly consistent between fields and show consistently higher values in the growing period that in the dormant period. Effective saturated conductivities for Toledo soils were more variable between years and the pattern within the growing period was also more variable than for Brookston soils.

Predictions of phosphorus transport were modelled concurrent with predictions of observed surface episodes of overland flow. For the application to Lanoue Weir #1 field, 12 predictions of observed surface episodes of overland flow were accompanied by 12 concurrent predictions of phosphorus transport.

6. SUMMARY

This final report has described a progression through five main areas of model development and application. These areas include: problem identification, stated objective, development of method, results and evaluation of results. Each area has been identified and dealt with in its' own section within this report. The introduction section identified the need for knowledge which constrains the ability to estimate seasonal variation of surface and sub-surface drainage flows. The objective section stated the intention of determining empirical values which affected estimations of surface and sub-surface drainage episodes. The method section defined the means in which to meet this objective. The results section showed the outcome of applying the predetermined method and the evaluation of results section identified the significance of the results.

As a direct consequence of going through the five main areas of model development and application, a majority of the intended results, which were outlined in the proposal written by Chisholm (1990) with respect to Andrew Marshall's contribution to modelling in Can-Ag's Land Planing studies, have been achieved. In order to aid the reader through intended results buried within the body of the five main areas of model development and application, each intended results outlined in the original proposal has been restated, and the location of the associated delivered result is located within the body of the report outlining the five areas of model development and application.

1. Analysis of field data for episodes of surface and sub-surface drainage observed during the land planing studies.

Figures 4.1 through 4.12 show the analysis of field data for episodes of surface drainage observed for each field in the Land Planing Studies. As well, Table 5.1 indicates periods of failure for recording surface drainage episodes due to either freezing, washout, instrument or installation failure.

Analysis of field data for episodes of sub-surface drainage did not take place in the body of this report since there were not any field data measurements of tile flow.

2. Analysis of total phosphorus and reactive phosphorus in drainage samples from land planing studies.

Tables 4.11 and 4.12 give observed total and filtered reactive phosphorus production quantities in water samples coming from Lanoue Weir#1 field for the period from May'89 to September'90. Concentrations of total and filtered reactive phosphorus have been determined for the other eleven fields in the Land Planing Studies for the period from May'89 to May'90 and this data is currently with Can-Ag Enterprises Limited.

3. Correct model predictions for the occurrence and timing of episodes of surface and sub-surface drainage episodes related to phosphorus transport.

Figures 4.1 through 4.12 show correct model predictions for the occurrence of episodes of surface drainage. In addition Table 4.10 gives a summary of the correct predictions of observed surface drainage episodes for the twelve fields in the Land Planing studies.

Correct model predictions for the timing of episodes did not take place in the body

of this report because optimization of the timing for each episode required another objective-method-results sequence. In order to calibrate the CREAMS model with the objective of correct timing of predictions, a second sensitivity analysis which deals with the hygrograph of overland flow needed to be completed. As well, a calibration process, again based on an overland flow hygrograph, would have been necessary.

Again, correct model predictions for either the occurrence or timing of surface or sub-surface flow did not take place since there were not any field data measurements of tile flow.

4. Analysis of the sensitivity of model predictions to model predictions.

Table 4.9 shows the results of the sensitivity analysis performed on each of the parameters in the modified hydrologic component and the body of the report discusses these results.

5. Identification of model parameters which affect modelling prediction accuracy for the occurrence and timing of surface and subsurface drainage episodes and related phosphorus transport.

Table 4.9 shows that the effective saturated conductivity and the surface roughness parameter had the greatest affect on modelling prediction accuracy for the occurrence of surface drainage episodes as compared to other parameters.

For the parameters which affect the correctness of model predictions, the following analyses will be completed.

6. Estimation of empirical values for these model parameters.

Figures 4.1 through 4.12 show the empirical values estimated for the effective saturated conductivity and surface roughness parameter for each of the fields in the Land Planing Studies.

7. Assessment of numerical values which is based upon current knowledge about the parameters involved.

&

8. Description of the model parameter variability with respect to seasons and physical differences between fields.

Part c) of Chapter 5 explains differences in effective saturated conductivity values and accuracy of correct predictions between fields and between seasons.

9. Analysis of the sensitivity of empirical values of the model parameters to season, crop and cultural practice.

Table 4.9 showed that the surface roughness parameter had the second greatest affect on modelling prediction accuracy for the occurrence of surface drainage episodes, and based on season, crop and cultural practice, empirical values for the surface roughness parameter were derived through consultation with a professional agronomist. These values for the surface roughness are given in figures 4.1 through 4.12. As well, Figures 4.1 through 4.12 and Tables E.1 and E.2 in Appendix E give the calibrated values of the effective saturated conductivity parameter for different seasons and crop and cultural practice.

10. Evaluation of the specific effects of land planing on the occurrence and magnitude of surface and subsurface drainage episodes and related phosphorus transport.

Figures 4.1 through 4.12 did not show any correlation between the modelled occurrence of a surface drainage episode and the difference between planed and unplaned field. Therefore, based upon the objective of determining empirical values which produce correct predictions of surface drainage episodes, modelled results did not show a difference between planed and unplaned fields.

At the request of TED Management, modelling was taken one step further, the empirical values, which were calibrated for each of the twelve field applications, were put through the modified hydrologic component once again, and the quantities of flow were recorded for each observed recording of overland runoff for the period May'89 to September'90. Figures 6.1 through 6.10 show the observed and modelled quantities of flow and gives them as a percentage of recorded precipitation. As well, Tables 6.1 through 6.10 give the observed and modelled peak flows and the EI value for each of the surface drainage episodes show on the graph.

Figure 6.1 through 6.4 show that the percentage of total modelled flow for the application to Lanoue's (28.5%) and Barrette's (23.7%) unplaned field is lower than the percentage of total modelled flow for the application to Lanoue's (30.7%) and Barrette's (32.3%) planned fields. Figures 6.1 through 6.10 and Tables 6.1 through 6.10 show other discrepancies between modelled and observed results, but these results are beyond the scope of this final modelling report.

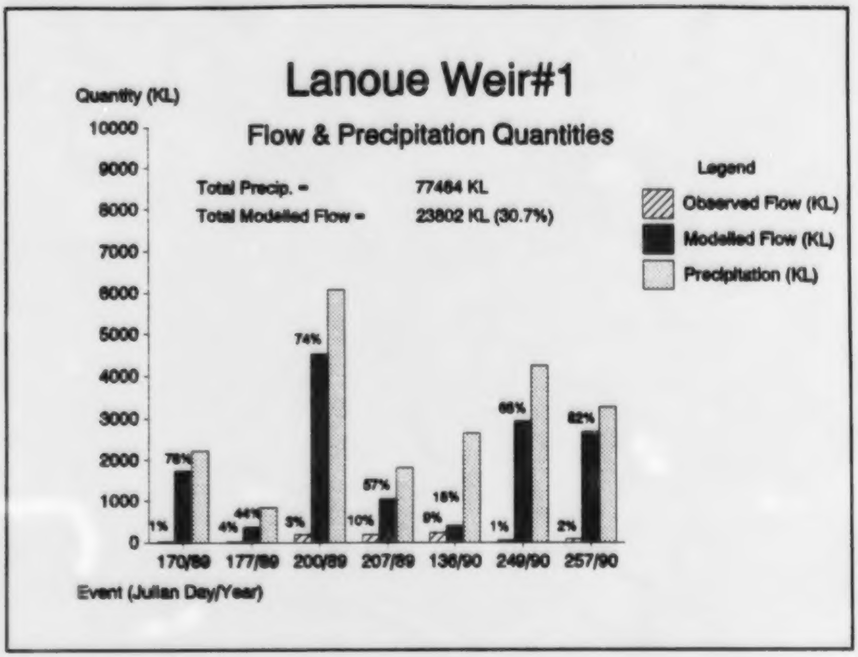


Figure 6.1 Flow and Precipitation Quantities: Lanoue Weir#1

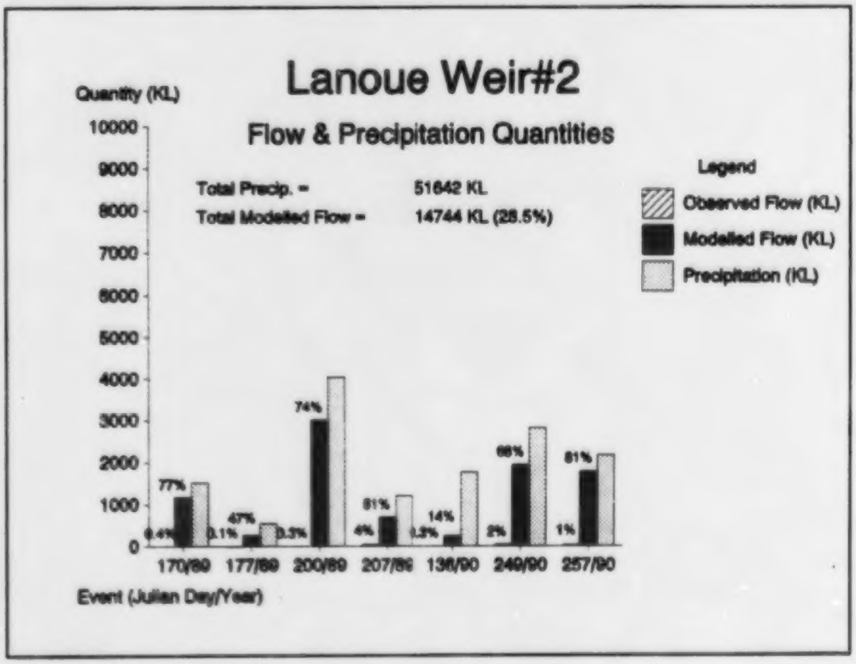
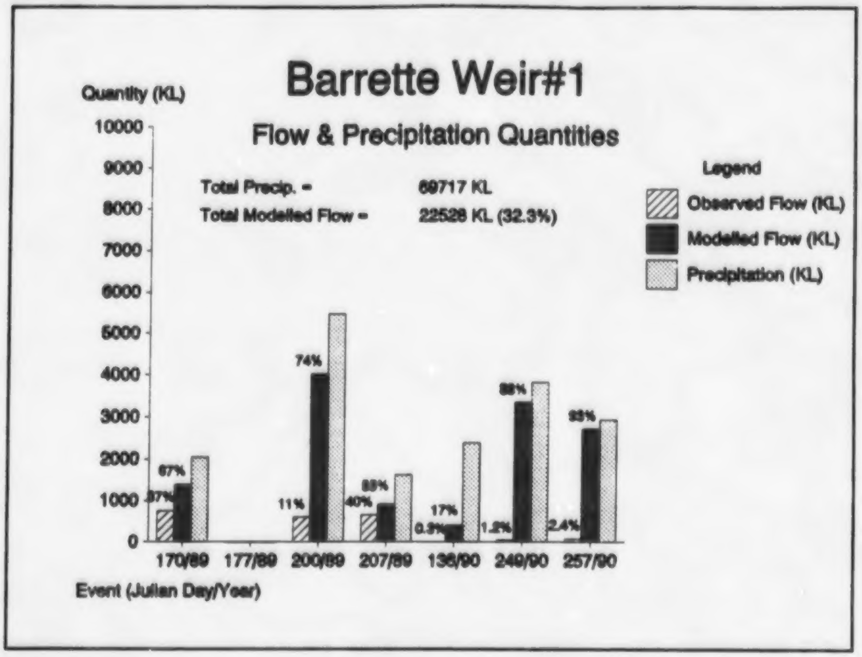
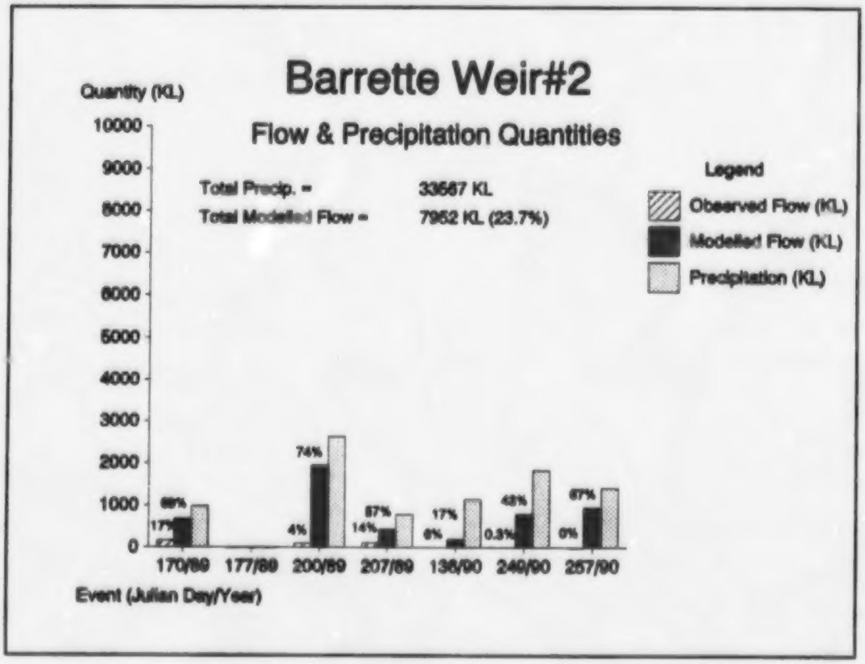


Figure 6.2 Flow and Precipitation Quantities: Lanoue Weir#2



<u>Figure 6.3</u> Flow and Precipitation Quantities: Barrette Weir#1



<u>Figure 6.4</u> Flow and Precipitation Quantities: Barrette Weir#2

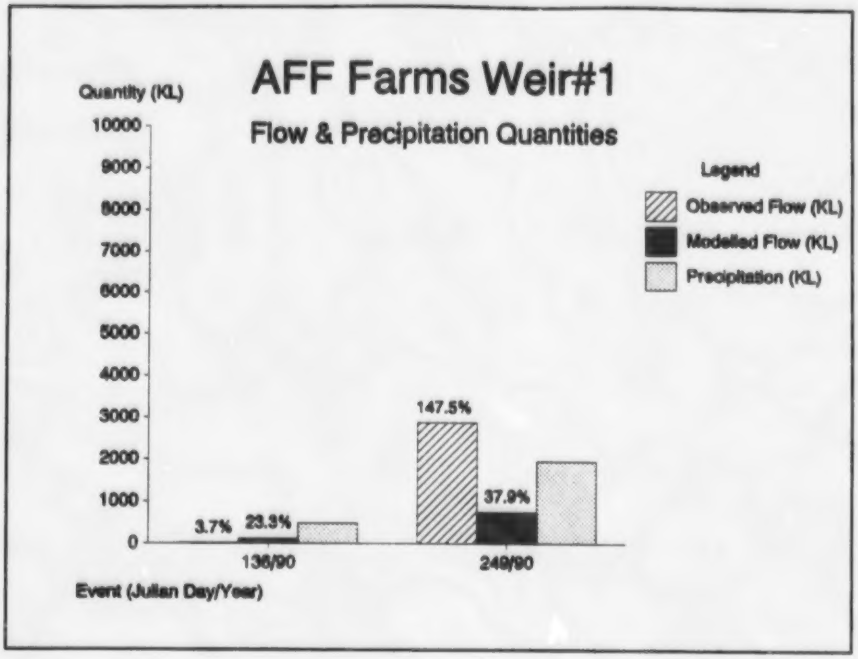


Figure 6.5 Flow and Precipitation Quantities: AFF Farms Weir#1

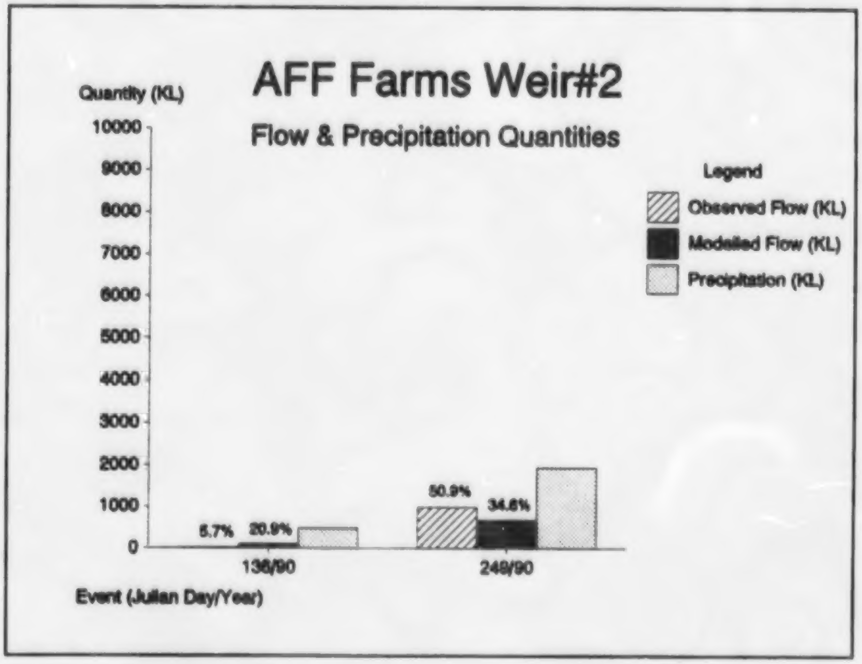


Figure 6.6 Flow and Precipitation Quantities: AFF Farms Weir#2

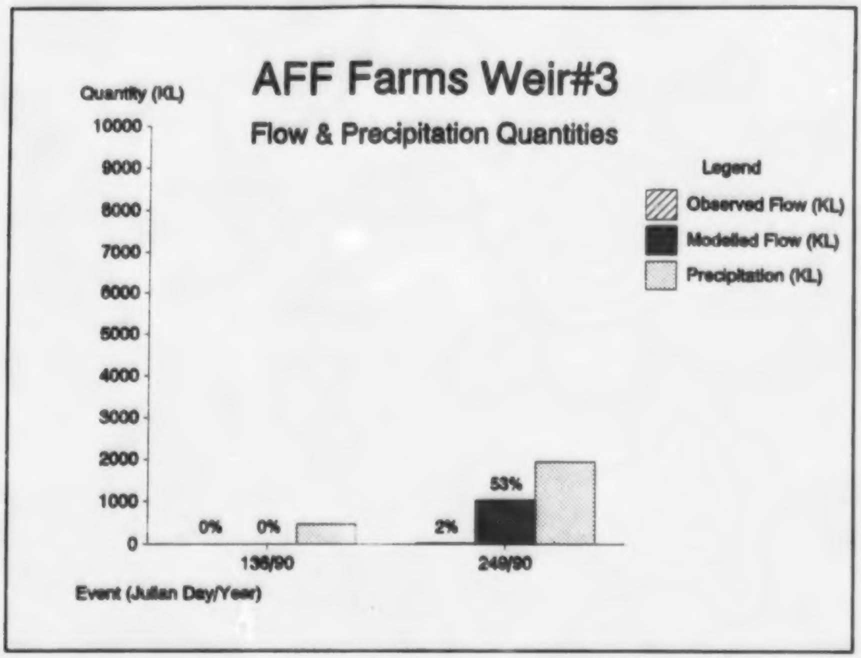


Figure 6.7 Flow and Precipitation Quantities: AFF Farms Weir#3

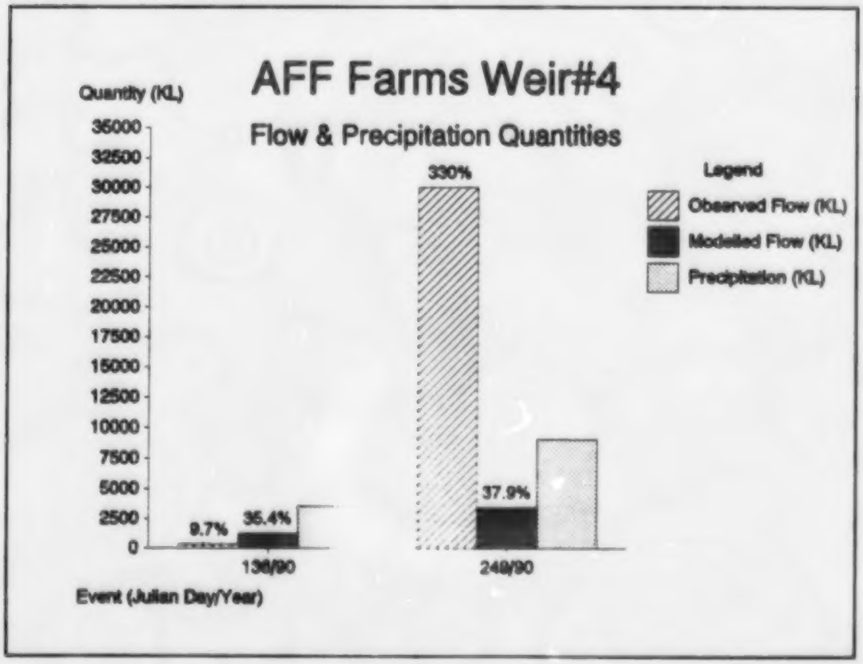


Figure 6.8 Flow and Precipitation Quantities: AFF Farms Weir#4

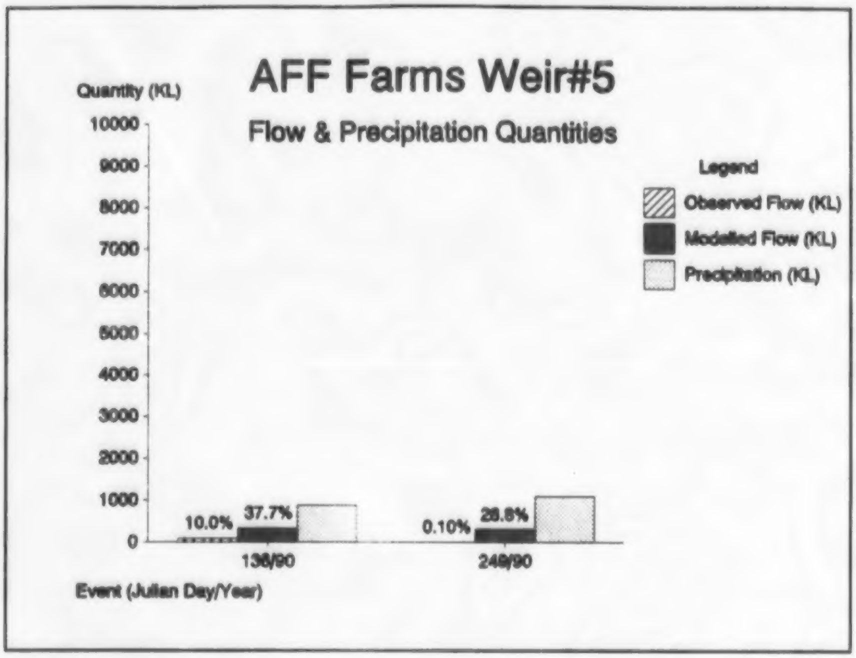


Figure 6.9 Flow and Precipitation Quantities: AFF Farms Weir#5

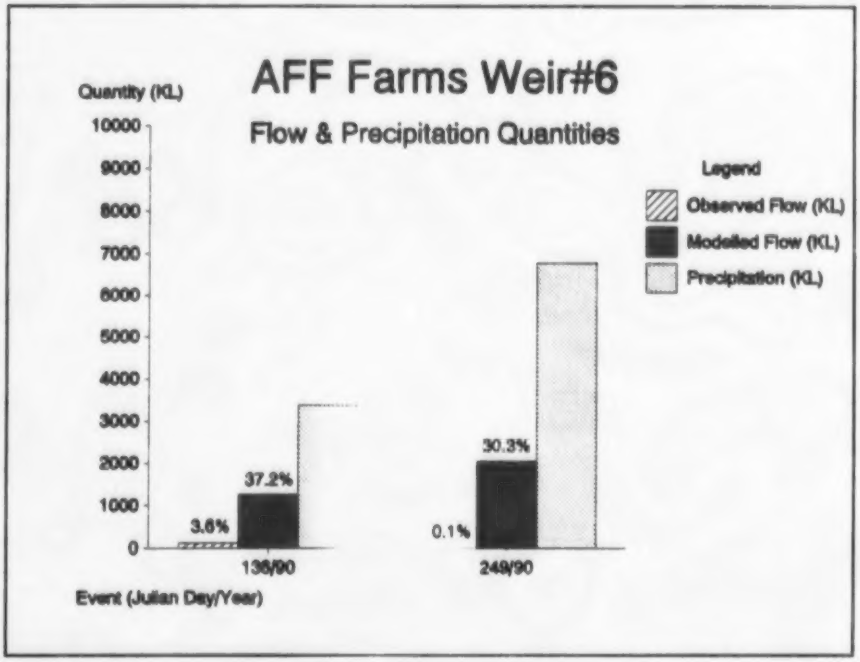


Figure 6.10 Flow and Precipitation Quantities: AFF Farms Weir#6

Table 6.1 Modelled and Observed Peaks: Lanoue Weir#1

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
170/89	70.0	3.0	13.0	2277
177/89	5.3	4.0	1.2	834
200/89	158.2	10.0	56.8	6072
207/89	18.0	4.0	4.5	1821
136/90	16.4	1.34	2.5	2650
249/90	22.1	0.8	130.7	4250
257/90	51.6	0.4	34.4	3263

Table 6.2 Modelled and Observed Peaks: Lanoue Weir#2

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
170/89	49.8	1.0	13.0	1581
177/89	4.1	0.2	1.2	557
200/89	110.4	2.0	56.8	4048
207/89	12.6	1.0	4.5	1214
136/90	17.2	0.2	2.5	1771
249/90	15.6	0.8	130.7	2833
257/90	35.8	0.4	34.4	2175

Table 6.3 Modelled and Observed Peaks: Barrette Weir#1

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
170/89	184.4	31.0	13.0	2049
177/89	-	-	1.2	751
200/89	573.6	21.0	56.8	5464
207/89	93.0	22.0	4.5	1639
136/90	23.6	0.2	2.5	2390
249/90	97.4	2.1	130.7	3825
257/90	192.9	4.4	34.4	2937

Table 6.4 Modelled and Observed Peaks: Barrette Weir#2

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
170/89	101.8	9.0	13.0	987
177/89	-	-	1.2	362
200/89	259.7	4.0	56.8	2631
207/89	54.9	2.0	4.5	789
136/90	13.5	0.8	2.5	1151
249/90	41.2	0.2	130.7	1841
257/90	75.5	(no flow)	34.4	1414

Table 6.5 Modelled and Observed Peaks: AFF Farms Weir#1

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
136/90	3.3	0.2	1.0	489
249/90	45.3	68.0	27.8	1941

Table 6.6 Modelled and Observed Peaks: AFF Farms Weir#2

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
136/90	2.9	0.4	1.0	489
249/90	41.9	19.0	27.8	1941

Table 6.7 Modelled and Observed Peaks: AFF Farms Weir#3

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
136/90	0	0	1.0	489
249/90	62.0	0.8	27.8	1941

Table 6.8 Modelled and Observed Peaks: AFF Farms Weir#4

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
136/90	23.7	2.6	1.0	3561
249/90	79.6	256.3	27.8	9081

Table 6.9 Modelled and Observed Peaks: AFF Farms Weir#5

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
136/90	6.6	1.2	1.0	890
249/90	7.5	0.1	27.8	1109

Table 6.10 Modelled and Observed Peaks: AFF Farms Weir#6

Date	Modelled Peak (L/s)	Observed Peak (L/s)	Rain (EI)	Rain (KL)
136/90	31.8	1.2	1.0	3386
249/90	62.9	0.1	27.8	6793

REFERENCES

BECK, M. B.. 1987. Water quality modelling: a review of the analysis of uncertainty. Water Resources Research, Vol. 23, No. 8, pp. 1393-1442.

CAN-AG ENTERPRISES LIMITED. 1988. Experimental design for the TED 10 Studies. Guelph, Ontario.

CHISHOLM, P S. 1990. Unsolicited proposal on modelling phosphorus transport. University of Guelph, Guelph, Ontario.

COOKE, R. A. C.. 1986. Numerical analysis of tile drainage from a cracked soil. MSc. Thesis, University of Guelph, Guelph, Ontario.

GREEN, W. H. and G. AMPT. 1911. Studies on soil physics, part I. - the flow of air and water through soils. J. Agricultural Sci., Vol. 4, pp. 1-24.

FRERE, M. H., E. H. SEELY and R. A. LEONARD. 1982. Modelling the quality of water from agricultural land. Hydrologic Modelling of Small Watersheds, Chap. 9, American Society of Agricultural Engineers.

HOLTAN, H. N.. 1961. A concept fro infiltration estimates in watershed engineering. USDA ARS Bul. 41-51, 25pp.

HORTON, R. E.. 1940. An approach toward physical interpretation of infiltration capacity. Trans. Am. Geophys. Union, Part IV: 693-694.

HUGGINS, L. F. and J. R. BURNEY. 1982. Surface runoff, storage and routing. Hydrologic Modelling of Small Watersheds, Chap. 5, American Society of Agricultural Engineers.

KNISEL, W. G., Jr.. 1980. CREAMS: a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U. S. Department of Agriculture, Conservation Research Report No. 26, 640 pp., illus.

JOY, D.. 1991. Personal communication. University of Guelph, Guelph, Ontario.

MacMILLAN, R.. 1990. Survey of unlevelled field. Can-Ag Enterprises Limited, Guelph, Ontario, Report: Land Reshaping of Lowland Clay Soils (March, 1990), pp. 13-18.

PETERS, E. J.. 1987. A finite element model for drainage in a Brookston clay. MSc. Thesis, University of Guelph, Guelph, Ontario.

RITCHIE, J. T.. 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resources Research, Vol. 8, No. 5, pp. 1204-1212.

RUDRA, R. P., W. T. DICKINSON and G. T. WALL. 1985. Application of the CREAMS model in southern Ontario conditions. Transactions of the ASAE, Vol. 28, pp. 1233-1240.

RUDRA, R. P., W. T. DICKINSON, and G. T. WALL. 1989. Evaluation of land use effects on surface soil hydraulic properties using CREAMS. Transactions of the ASAE, Vol. 32, pp. 1295-1302.

SCHROETER, H. O. and H. R. WHITELEY. 1988. GAWSER: Guelph Agricultural Watershed Storm-Event Runoff model. School of Engineering, University of Guelph, Guelph, Ontario.

SKAGGS, R. W.. 1980. Drainmod-reference report: methods for design and evaluation of drainage-water management systems for soils with high water tables. USDA-SCS, South National Technical Center, Fort Worth, Texas.

SMITH, R. E. and J. R. WILLIAMS. 1980. Simulation of the surface water hydrology. CREAMS, Chap. 2, U. S. Department of Agriculture, Conservation Research Report No. 26, 640 pp.

UNITED STATES SOIL CONSERVATION SERVICE. 1974. Design of small dams. United States Bureau of the Interior. Table A-2, pp. 536.

APPENDIX A

Experimental Design for Can-Ag's TED 10 Studies:
(Can-Ag Enterprises Limited, 1988)

The following is a summary of main hypotheses, treatments and sampling for the project. The study is designed to provide results on four "case studies" with statistical analysis to be conducted where appropriate.

Null Hypotheses:

A. Seasonal and annual runoff characteristics (timing, volumes, quality) are not affected by land planing. If rejected, identify optimal conditions for minimizing environmental impact in quantitative terms.

B. Various crops routinely grown by farmers will not respond differently to land planing. If rejected, identify optimal treatment for each crop in quantitative terms.

C. Various tillage practices implemented by farmers and resultant crop residues do not affect runoff characteristics differently on planed vs. unplaned fields. If rejected, quantify the effect.

D. Tile drainage does not benefit planed fields. If rejected, quantify the effect.

E. Soil conditions in planed fields do not change following planing. If rejected, describe the changes.

F. Spatial variation in runoff within a planed and unplaned field are similar. If rejected, quantify the effects.

Treatments:

1. Four paired fields each comprising a planed and unplaned field. Three fields (No. 2, 3, 4) were planed three or more years ago: field No. 1 was planed in 1988. Furthermore, the former three are tile drained: the latter is not.

2. In 1989, the crops will be:

   Planed Field 1: soy 2: tomatoes 3: wheat & clover
   4: soy

   Because wheat is already planted, crops cannot be changed for 1989 without considerable expense.

In 1990, we could try to negotiate to have soybeans throughout. This means changing one field from corn to soybeans. Then in 1991, we would try to have corn on all fields.

3. Tillage practices employed by all the farmers are considered to be conservation oriented. Therefore, we propose to focus on amount of trash cover, surface roughness, whether there is inter-row cultivation after planting, and whether there is fall tillage. After 1989 harvest, we would try to have identical tillage on paired fields.

Statistical Analysis:

The study is oriented towards case studies in which runoff measurements are "event" based. Results from events will be extrapolated to estimate seasonal and annual totals with the aid of models, continuous rainfall data and frequent visual observations. The following statistical analysis can be conducted for each of the hypothesis.

Re: Null hypothesis A: Treat each of four pairs as a replicate, analyzed over 3 or more years starting in 1989.

Re: Null hypothesis B: Can only compare tomatoes on field pair #2 in 1989; all fields under soybeans in 1990; and all fields under corn in 1991, conditions permitting.

Re: Null hypothesis C: Could be similar to "B" above, but may have differences in cultivation among four pairs of fields.

Re: Null hypothesis D: The best we can do is compare field pair #1 against all others. This is also limited by different soil types on field pair #1 vs. all others. There may be a possibility of dividing fields in pair #1 to establish two replicates.

Re: Null hypothesis E: This can be monitored only at the levelled field #1. Can examine changes over time and make comparisons against the unplaned field. Two transects of 3 sites per transects will serve as 2 replicated within each field of the pair.

Re: Null hypothesis F: Essentially same as for E, above.

Sampling Scheme

Five major parameters will be monitored:

1. Soil conditions: characteristics, erodibility, fertility.

2. Hydrology: timing, volumes, quality, source areas, water tables.

3. Climate: precipitation, temperature.

4. Agronomy: inputs, crop yields and quality.

5. Management: levelling history, cropping program, economics.

Following is an outline of sampling and observations intensities for each parameter.

1. Soils

- Baseline characterization: detailed soil survey, laser survey of unplaned fields, description and sampling of major soil types plus 12 sites for the spatial analysis, fertility sampling of fields.

- Repeated characterization: trash cover, surface roughness, moisture status during "events" being monitored. Annual soil fertility sampling.

- On field pair #1, soil compaction changes over time would be monitored based on structure, bulk density and penetrometer resistance.

2. Hydrology

- "Event" monitoring during 6 periods of the year as follows:

March	-	snow melt or rain, frozen soil
April	-	melt or rains, thawed soils, pre-cultivation
June	-	spring storms, little crop cover
Jul - Aug	-	summer storms, after fall cultivation
Oct - Nov	-	fall storms, after fall cultivation
Jan - Feb	-	winter snow cover, frozen soil

- Monitoring and sampling per event (up to 5 days per event) to include:

  - Field pair #1

    - 2 automatic flow recorders (at 1 V-notch weir per field)
    - monitoring sediment traps (6 traps per field)
    - collect samples three times or more per day at V-notch weirs and from sediment traps

  - Field pairs 2, 3 and 4

    - 1 V-notch weir per field monitored manually
    - collect samples 3 times or more per day at V-notch

- Define "source" areas for runoff by visual inspection, aided by topographical maps, time of sampling

- In addition, note runoff occurrences between "events" being monitored. Also, note when tile drains are discharging.

- Monitor water tables (3 observation wells per field, to 1.5m)

3. Climate

- Precipitation

  - continuous rainfall: 3 gauges representing field pair 1, 2 and 3, and 4

  - if possible, set-up winter rain gauges

  - measure snow-pack

  - obtain data met. stations at Harrow, Ontario

- Temperature

  - daily maximum and minimum temperatures at three locations as for precipitation.

4. Agronomy

- tillage practices (operation, date, soil conditions, equipment)

- weeds and pests (abundance and control)

- cropping practices (varieties, rotations)

- fertilization (rates and methods)

- crop yields, variation, quality (field yields and micro-plot measurements)

5. Management

- levelling history (surveys plans, levelling method and costs, maintenance)

- perceived benefits of levelling

- planning allocation of resources

- cropping choices especially as related to land levelling

- economic (re: levelling, production, conservation)

Features of the Study

Results from the case studies will be combined with statistical analyses, as appropriate, to focus on four important areas.

1. Develop effective and efficient monitoring and sampling techniques, including: relating "events" to long term climatic patterns, winter runoff, on-farm practices, use of soil traps on nearly level terrain, and others.

2. Test and adapt computer models to aid in data analysis, to extrapolate findings from events to seasons, and to recommend procedures for future application.

3. To prepare guidelines for improving land planing techniques (considering drain courses, topsoil stripping, compaction, subsoiling, etc.)

4. To examine the advantage and disadvantage of land planing considering:

   - economics
   - management practices
   - environmental impact (re: phosphorus, sediments)

APPENDIX B

Modifying the CREAMS Model

The subroutine called PRSWD, which disclosed model estimates for daily soil water data, was added to the CREAMS model. The PRSWD subroutine recorded the daily soil water values and the associated Julian day in an output file. Below, Figure B.1 shows the PRSWD subroutine, and Figure B.2 shows an output file, resulting from the subroutine.

```
      SUBROUTINE PRSWD(BDATE)
      INTEGER BEGY,KSTART,BDATE,I1
      REAL    BBDATE,BBEGY,KKSTART
      COMMON /BILL/ SWD(366)
      BEGY    =BDATE/1000
      KSTART  =BDATE-BEGY*1000
      BBDATE  =REAL(BDATE)
      BBEGY   =REAL(BEGY)
      KKSTART =REAL(KSTART)
      WRITE (5,100) BBDATE,BBEGY,KKSTART
      DO 10 I =KSTART,364,2
      I1      =I+1
      WRITE (5,200) I,SWD(I),I1,SWD(I1)
      10  CONTINUE
      RETURN
100   FORMAT (/,8HBDATE IS,F6.0,/,7HBEGY IS,F6.0,/,9HKSTART
      IS,F6.0)
200   FORMAT (I6,2X,F6.3,5X,I6,2X,F6.3)
      END
```

Figure B.1 Subroutine PRSWD

An example of a stepwise continuous application is as follows. In Figure B.2 the value 3.310(in.) for the last Julian day (30) was divided by the total initial storage value (in.) given in the modified hydrologic component's output file. This value would then be used as the input for the BST parameter (portion of plant-available water storage at start) at the start of the next seasonal interval.

```
BDATE IS90001.
BEGY IS   90.
KSTART IS    1.
     1    .000        2   4.060
     3   4.022        4   3.988
     5   3.957        6   3.929
     7   3.902        8   3.877
     9   3.852       10   3.826
    11   3.800       12   3.780
    13   3.754       14   3.728
    15   3.701       16   3.674
    17   3.647       18   3.620
    19   3.593       20   3.565
    21   3.536       22   3.508
    23   3.479       24   3.450
    25   3.423       26   3.398
    27   3.374       28   3.352
    29   3.331       30   3.310
```

Figure B.2 Subroutine PRSWD Output File

Note: The CREAMS User's Manual provides two different definitions for the parameter FUL. On page 173 of the User's Manual, the parameter FUL is described as the portion of plant-available water storage filled at field capacity, and on page 174 of the User's Manual, the parameter FUL is described as the fraction

of pore space filled at field capacity. After reviewing the CREAMS source code, the first description of FUL, as the portion of plant-available water storage filled at field capacity, was found more nearly correct subject to the unusual usage of including soil water between saturation and field capacity within the category of "plant-available water". Figure B.3 shows the source code used in determining the correct definition of the FUL parameter.

```
1    ULS    =DS*(POROS-BR15)
2    ULP    =DP*(POROS-BR15)*FUL
3    UL     =ULS+ULP
4    SW     =BST*ULS
5    PW     =BST*ULP
6    TSW    =PW+SW
```

<u>where</u>:

DS:	depth of soil surface
DP:	depth of remaining root zone
POROS:	soil porosity
BR15:	immobile soil water content
FUL:	portion of plant-available water storage at field capacity
BST:	portion of plant-available water storage filled at start
ULS:	upper limit of storage in surface layers
ULP:	upper limit of storage in remaining root zone

<u>Figure B.3</u> Portion of CREAMS Source Code

<u>Note</u>: In line 2 FUL enters as a proportion of the "plant-available water" (defined as (layer depth)*(porosity-immobile water content)), not as a proportion of total porosity. Further note that for reasons not explained FUL is not applied to the depth of surface soil.

APPENDIX C

Numerical Values for Crop Parameters

Tables C.1, C.2 and C.3, below, give the numerical values for crop parameters, interpreted from previous studies for the observed crop species. Table C.1 gives the numerical values for the depth of root soil zone, surface roughness and winter cover factor for 1989 and 1990. Table C.2 gives the leaf area index values for the year 1989, and Table C.3 gives the same values for the year 1990.

Table C.1 Depth of Root Soil Zone, Surface Roughness and Winter Cover Factor Values For 1989 and 1990

Field Application	Depth of Root Soil Zone (cm) 1989	1990	Surface Roughness (Manning's n) 1989	1990	Winter Cover Factor 1989 & 1990
Lanoue W1	61.0	122.0	0.120	0.098	1.0
Lanoue W2	61.0	122.0	0.120	0.098	1.0
Barrette W1	45.7	91.5	0.120	0.120	1.0
Barrette W2	45.7	91.5	0.120	0.120	1.0
Doyle W1	91.5	91.5	0.120	0.120	1.0
Doyle W2	122.0	91.5	0.098	0.120	1.0
AFF Farms W1	30.5	122.0	0.068	0.098	1.0
AFF Farms W2	30.5	122.0	0.068	0.098	1.0
AFF Farms W3	30.5	122.0	0.068	0.098	1.0
AFF Farms W4	91.5	122.0	0.120	0.098	1.0
AFF Farms W5	91.5	122.0	0.120	0.098	1.0
AFF Farms W6	91.5	122.0	0.120	0.098	1.0

Table C.2 Leaf Area Index Values for 1989 by Julian Day

Field Application	day 146	day 174	day 203	day 232	day 261	day 290	day 305
Lanoue W1	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Lanoue W2	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Barrette W1	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Barrette W2	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Doyle W1	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Doyle W2	0.00	0.90	1.30	0.00	0.00	0.00	0.00
AFF Farms W1	0.00	0.28	0.45	0.50	0.50	0.50	0.00
AFF Farms W2	0.00	0.28	0.45	0.50	0.50	0.50	0.00
AFF Farms W3	0.00	0.28	0.45	0.50	0.50	0.50	0.00
AFF Farms W4	0.00	0.19	0.49	2.97	2.72	0.00	0.00
AFF Farms W5	0.00	0.19	0.49	2.97	2.72	0.00	0.00
AFF Farms W6	0.00	0.19	0.49	2.97	2.72	0.00	0.00

Table C.3 Leaf Area Index Values for 1990 by Julian Day

Field Application	day 148	day 174	day 203	day 232	day 261	day 290	day 308
Lanoue W1	0.00	0.90	1.30	0.00	0.00	0.00	0.00
Lanoue W2	0.00	0.90	1.30	0.00	0.00	0.00	0.00
Barrette W1	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Barrette W2	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Doyle W1	0.00	0.19	0.49	2.97	2.72	0.00	0.00
Doyle W2	0.00	0.19	0.49	2.97	2.72	0.00	0.00
AFF Farms W1	0.00	0.90	1.30	0.00	0.00	0.00	0.00
AFF Farms W2	0.00	0.90	1.30	0.00	0.00	0.00	0.00
AFF Farms W3	0.00	0.90	1.30	0.00	0.00	0.00	0.00
AFF Farms W4	0.00	0.90	1.30	0.00	0.00	0.00	0.00
AFF Farms W5	0.00	0.90	1.30	0.00	0.00	0.00	0.00
AFF Farms W6	0.00	0.90	1.30	0.00	0.00	0.00	0.00

APPENDIX D

Numerical Values for Soil Parameters

Tables D.1 and D.2, below, give the numerical values for soil parameters, interpreted from the textural classification and soil pit survey reports. Table D.1 gives the numerical values for the effective saturated conductivity parameter, effective capillary tension parameter, porosity parameter and the fraction of the plant-available water storage

Table D.1 Soil Values

Field Application	Effective Saturated Conduct. (cm/hr)	Effective Capillary Tension (cm)	Porosity (cm/cm)	Fraction of Water Storage Filled at Start (March 31/89)
Lanoue W1	0.102	50.8	0.480	1.00
Lanoue W2	0.102	50.8	0.480	1.00
Barrette W1	0.102	50.8	0.480	1.00
Barrette W2	0.102	50.8	0.480	1.00
Doyle W1	0.102	50.8	0.480	1.00
Doyle W2	0.102	50.8	0.480	1.00
AFF Farms W1	0.102	50.8	0.480	1.00
AFF Farms W2	0.102	50.8	0.480	1.00
AFF Farms W3	0.102	50.8	0.480	1.00
AFF Farms W4	0.102	50.8	0.480	1.00
AFF Farms W5	0.102	50.8	0.480	1.00
AFF Farms W6	0.102	50.8	0.480	1.00

filled when simulation begins parameter. Table D.2 gives the numerical values for the depth of soil surface parameter, immobile water content parameter, portion of plant-available water storage filled at field capacity parameter and the soil evaporation parameter.

<u>Table D.2</u> Soil Values

Field Application	Depth of Soil Surface (cm)	Immobile Water Content (cm/cm)	Portion of Plant-Avail. Storage Filled @ F.C.	Soil Evaporation Factor (mm/day$^{(1/2)}$)
Lanoue W1	9.00	0.210	0.722	3.50
Lanoue W2	13.00	0.210	0.722	3.50
Barrette W1	10.00	0.210	0.722	3.50
Barrette W2	15.00	0.210	0.722	3.50
Doyle W1	15.00	0.210	0.722	3.50
Doyle W2	8.00	0.210	0.722	3.50
AFF Farms W1	10.00	0.210	0.722	3.50
AFF Farms W2	13.00	0.210	0.722	3.50
AFF Farms W3	13.00	0.210	0.722	3.50
AFF Farms W4	11.00	0.210	0.722	3.50
AFF Farms W5	13.00	0.210	0.722	3.50
AFF Farms W6	13.00	0.210	0.722	3.50

APPENDIX E

Effective Saturated Conductivity

Figures 4.1 through 4.12 show the distribution of effective saturated conductivity values calibrated for each seasonal interval within each study field. Based upon Figures 4.1 through 4.12, Tables E.1 and E.2 were prepared to present a summary of the effective saturated conductivity values calibrated for each season interval within each study field.

Table E.1 Distribution of Effective Saturated Conductivity: 1989

Field Application	Crop	S1 0415	S2 0515	S3 0615	S4 0715	S5 0815	S6 0827	S7 1231
Lanoue W1	tomato	0.13	0.38	0.13	0.08	0.13	0.13	0.13
Lanoue W2	tomato	0.13	0.38	0.13	0.08	0.13	0.13	0.13
Barrette W1	corn	0.13	0.38	0.05	0.13	0.13	1.01	0.13
Barrette W2	corn	0.13	0.38	0.05	0.13	0.13	1.01	0.13
Doyle W1	soybeans	0.13	0.38	0.51	0.13	1.27	0.51	0.13
Doyle W2	wheat	0.25	0.38	0.51	0.13	1.27	0.51	0.03
AFF Farms W1	crop failure	0.13	0.38	1.64	0.63	0.13	0.25	0.25
AFF Farms W2	crop failure	0.13	0.38	1.77	0.76	0.13	0.25	0.25
AFF Farms W3	crop failure	0.13	0.38	1.77	0.76	0.13	0.25	0.25
AFF Farms W4	soybeans	0.13	0.38	0.51	0.76	0.13	0.13	0.13
AFF Farms W5	soybeans	0.13	0.38	0.51	0.76	0.13	0.25	0.38
AFF Farms W6	soybeans	0.13	0.38	0.63	0.89	0.13	0.25	0.13

In Tables E.1 and E.2, the end day of each seasonal interval is given by month and calendar date, and the effective saturated conductivity values are given in mm/hr.

Table E.2 Distribution of Effective Saturated Conductivity: 1990

Field Application	Crop	*S1 0415	*S2 0515	*S3 0615	*S4 0715	*S5 0815	*S6 0927
Lanoue W1	wheat	0.08	0.05	0.13	0.13	0.25	0.13
Lanoue W2	wheat	0.08	0.63	0.13	0.13	0.25	0.13
Barrette W1	soybeans	0.03	0.13	0.13	0.25	0.51	0.25
Barrette W2	soybeans	0.13	0.38	0.13	0.25	0.63	0.25
Doyle W1	soybeans	0.13	0.63	0.25	0.38	0.38	1.01
Doyle W2	soybeans	0.13	0.03	0.25	0.38	0.38	0.13
AFF Farms W1	wheat	0.08	0.13	0.13	0.51	0.89	1.01
AFF Farms W2	wheat	0.03	0.13	0.13	0.51	0.89	1.27
AFF Farms W3	wheat	0.03	0.13	0.13	0.51	0.89	1.27
AFF Farms W4	wheat	0.03	0.08	0.08	0.38	0.51	0.76
AFF Farms W5	wheat	0.03	0.51	0.08	0.38	0.51	1.27
AFF Farms W6	wheat	0.03	0.51	0.08	0.51	0.63	1.27